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CONTENTS

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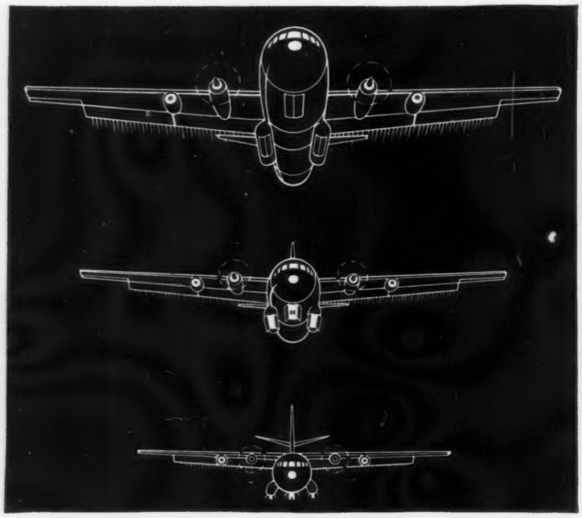
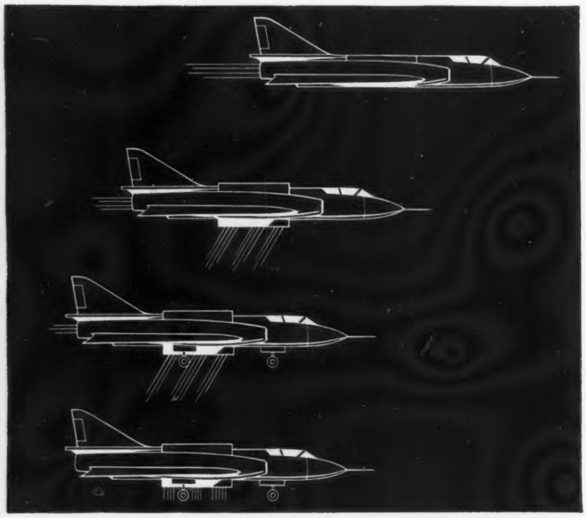
ROLLS-ROYCE

JET LIFT AND PROPULSION ENGINES
have been specified for
NEW STOL AND VTOL MILITARY AIRCRAFT



STOL
Short Take-off and Landing



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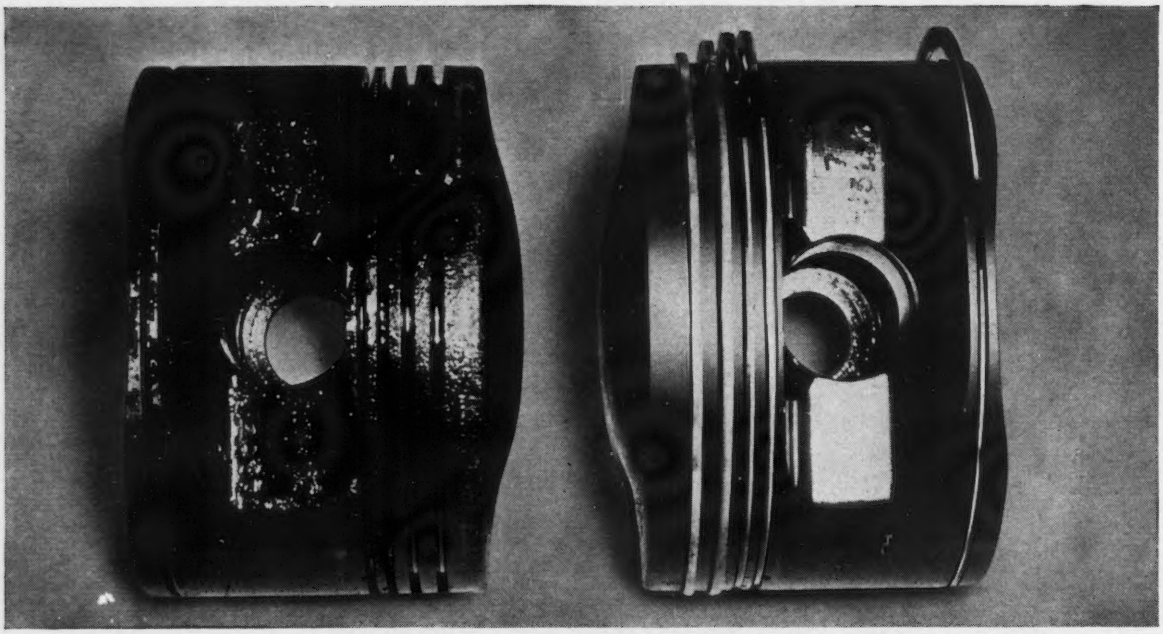

Left: Piston from engine using straight mineral oil after 1,000 hours; note sludge and coke.
Right: Piston from same aircraft after 1,000 hours on AeroShell Oil W.

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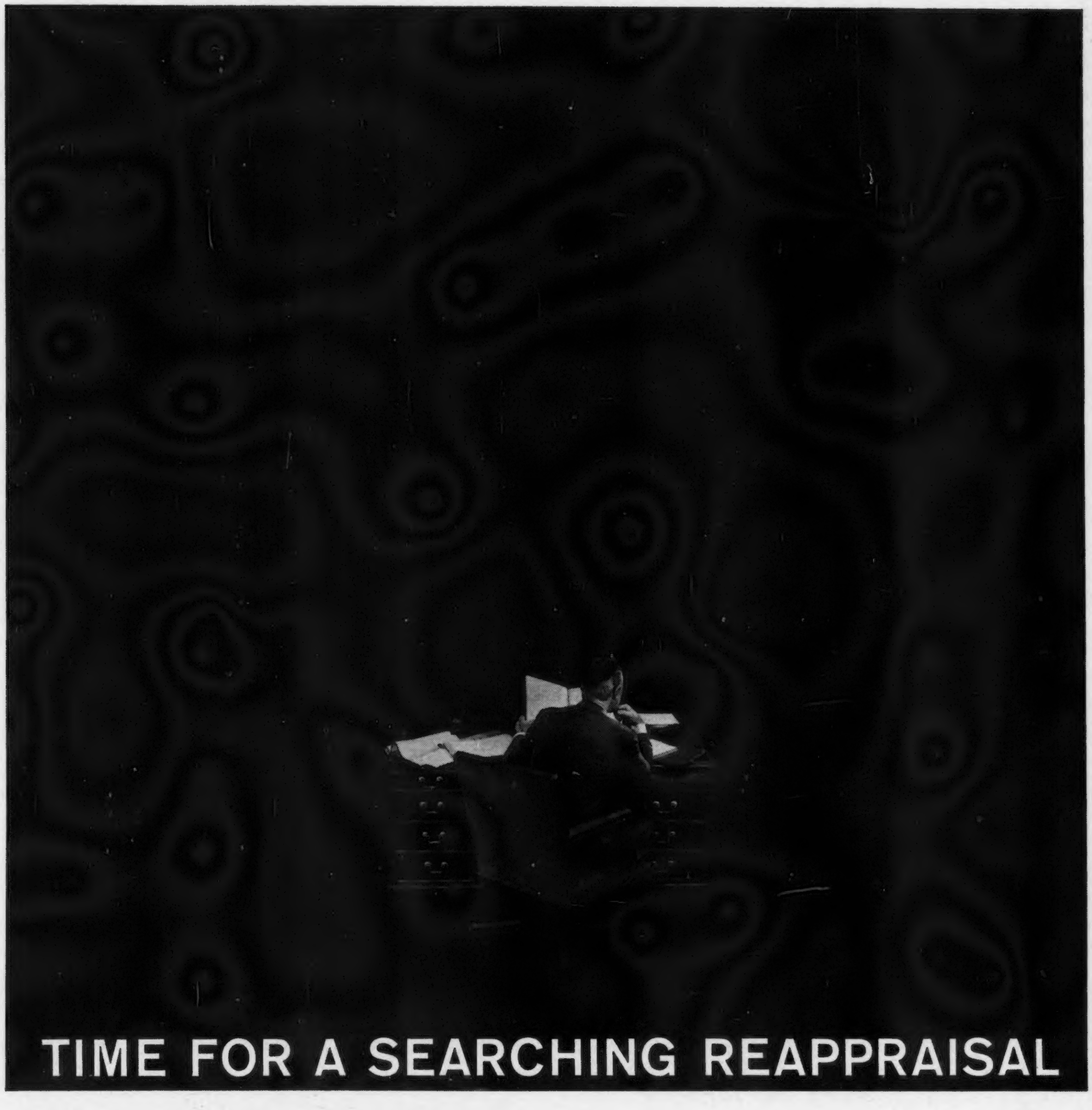

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JOURNAL

ASPECTS OF EFFICIENT PROPELLER SELECTION WITH PARTICULAR REFERENCE TO MAN-POWERED AIRCRAFT†

by R. H. Wickens*

National Aeronautical Establishment

SUMMARY

The success of a man-powered aircraft depends largely upon the efficiency of the propulsive system. The propeller as a means of thrust generation is discussed in terms of the optimum advance ratio, solidity and power coefficient. Levels of efficiency attained in practice are compared with the theoretical values of the ideal propeller, and the various aspects of efficient blade design are discussed.

Since the propeller of a man-powered aircraft may operate at Reynolds numbers lower than those usually encountered in practice, particular attention is paid to the boundary layer and scale effects.

INTRODUCTION

RECENTLY, considerable attention has been focussed on the attempts to fly by the power of human muscle alone. Early efforts, in which aircraft were actually built, flights attempted, and results recorded, are described in References (1) and (2).

The success of an aircraft of this type depends in part upon the skillful design of a strong, lightweight structure, and partly upon the aerodynamic efficiency of the lifting and propulsive systems. In the past few years renewed interest in ultra-light, "home built" aircraft has led to the development of optimum airframe structures. Reference (3) is typical of the approach to this problem. Parallel efforts to increase the performance of sailplanes has also resulted in specialized techniques regarding the aerodynamic problem. The development of highly efficient aerofoil sections, in particular, has received much attention[4, 5, 6]. In both of these areas, structural and aerodynamic, the peak performance may have been reached for the conventional "aeroplane" type of configuration; the successful man-powered aircraft may, of necessity, have to be unconventional in principle.

Interest in man-powered aircraft has recently been stimulated by the Kremer Competition[7], in which a considerable sum has been offered for the construction and successful flight of such an aircraft. Although no such flights have been attempted at the time of writing, several proposals and design studies have been published. One such study is described in Reference (8), in which the merits of a particular proposed design are studied in terms of the power and endurance available from human muscle.

Aspects of the generation of power by humans are discussed in a review article by Wilkie[9]. He points out that the production of such power is accompanied by limits of endurance which vary inversely as the maximum output. Levels of power as high as 2 bhp may be attained, but for a duration of only 6-10 seconds. Lower levels of power may be attained for a longer time, and the author states that a minimum level of approximately 0.5 bhp may be maintained indefinitely by a person of average physical capacity and in normal good health. This steady state output has also been shown to depend somewhat upon the mode of power generation (i.e. legs alone vs legs and arms). Likewise, the short bursts of power previously mentioned may depend critically upon the athletic level of the individual; for example, the figure of 0.5 bhp can be doubled for approximately ¾ minute by the physical capacity of a national amateur, but

†Received 23rd May, 1961.
*Asst. Research Officer, Low Speed Aerodynamics

a world professional athlete may attain a further endurance of 1¼ minutes.

Optimization studies and design proposals submitted thus far, as well as the two aircraft built and flown, have inferred that the man-powered vehicle should approximate the conventional aeroplane with independent lifting and propulsive systems. While the design and aerodynamic performance of such a concept is a well-known art, it may not necessarily result in the optimum low speed aeroplane. Nonweiler[8] concludes that efforts should be made to investigate other configurations, such as helicopters. Reference (10) also discusses the aspects of many aerodynamic systems in which lift and propulsion are integrated[a].

Regardless of the design concept of the aeroplane, the over-all performance will depend upon the effectiveness of the propeller, whether used in the lifting or thrusting role. The propeller used as a means of thrust generation only has been employed for many years; much literature, both theoretical and experimental, is available, and its operation is well understood. For these reasons this article will deal with the various aspects of the design of efficient propellers, operating in the conventional (i.e. cruising) sense. It is intended to show, by standard calculation methods, how the optimum efficiency is affected by design power coefficient, advance ratio and other parameters. Special attention is paid to peculiar operating conditions of a propeller for a man-powered aircraft, such as the abnormally low blade Reynolds numbers. Effects such as these may also have some correlation with other, less conventional configurations.

While keeping in mind the final application of such a propeller, it is not intended to limit the study by the practicability of the mechanical design (e.g. variable pitch), but it is hoped that the data shown will present a useful summary of propeller design criteria.

LIST OF SYMBOLS

A	disc area
B	number of blades
c	propeller mean chord, ft
C_{D_f}	aeroplane profile drag coefficient
C_{D_o}	section minimum drag coefficient
$\bar{C}_D$, $\bar{C}_L$	propeller mean lift and drag coefficients
C_P	propeller power coefficient $P/\rho N^3D^5$
C_T	thrust coefficient, $T/\rho N^2D^4$
D	propeller diameter, ft
E	slipstream induced power, hp
J	advance ratio V/ND
K	induced drag factor
N	propeller speed, rev/sec, rad/sec
P	power, hp
q	dynamic pressure, $\rho V^2/2$, lb/ft²
R	propeller tip radius $(D/2)$
r	representative station radius
T	thrust, lb
u	propeller inflow velocity, ft/sec
u_1	slipstream velocity, ft/sec
V	flight velocity, ft/sec
w	wing loading, lb/ft²
W	aircraft weight, lb
α	angle of attack
η	propeller efficiency
ρ	air density, lb/ft³
σ	propeller solidity, $2Bc/\pi D$
ν	kinematic viscosity
Ω	propeller angular velocity
Re	Reynolds number, Vc/ν, except where otherwise stated
X_R	non-dimensional root radius

[a]Eq. (3) of this article indicates that, for aircraft of high aspect ratio, level flight at minimum power may be limited by lift coefficients well below those required to sustain the aircraft.

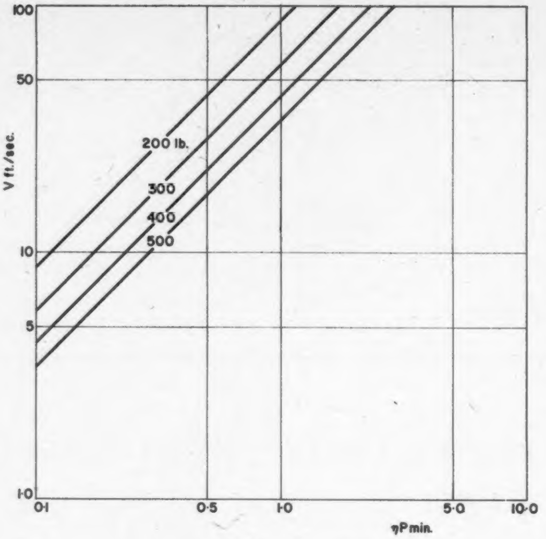


Figure 1
Variation of flight velocity with minimum power
$C_{D_f} = 0.014$, $K = 0.014$

POWER REQUIRED AND AVAILABLE FOR A MAN-POWERED AIRCRAFT

Aeroplane power requirements

In order to introduce the problem of propeller selection and design, it might be useful to specify a hypothetical aeroplane of conventional design and to summarize the effects of drag, weight and wing-loading upon the power requirements. Assuming a parabolic variation of drag with lift, theoretical expressions for minimum power and thrust, and speed for minimum power, are written as follows:

$$P_{\min} = 2.48\,(w/\rho)^{1/2}\,K^{3/4}\,C_{Df}^{1/4}\,W/\eta \tag{1}$$

$$T_{P_{\min}} = 2.31\,W\sqrt{C_{Df}\,K} \tag{2}$$

$$(q/w)_{P_{\min}} = \sqrt{K/3C_{Df}} \tag{3}$$

From Eq. (1) it is seen that minimum power for steady level flight is affected most critically by the all-up weight W, and to a lesser degree by the profile drag C_{D_f}. For an aeroplane of a given wing area and aspect ratio, with a fixed induced drag factor K, the effects of relative changes in W and C_{D_f} may be established. For example, Reference (8) gives a value of 0.014 for the minimum drag coefficient of a proposed man-powered aircraft, while several highly efficient sailplanes have values of C_{D_f} as low as 0.008. These values represent a 15% spread in the power requirements of two otherwise similar aircraft.

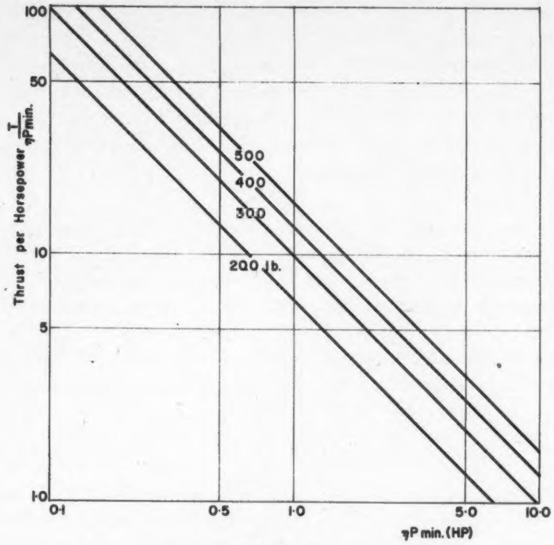


Figure 2
Variation of thrust loading with minimum power
$C_{D_f} = 0.014, K = 0.014$

Figures 1 and 2 illustrate the effect of weight on thrust/hp and flight velocity for minimum power. The abcissa in both cases is power required by the aircraft, although in Figure 2 both $T/\eta P_{min}$ and ηP_{min} may be interpreted on the basis of total power required by the propeller. Constant values of C_{D_f} and K have been taken to be 0.014.

On the basis of 1 bhp available at the propeller shaft, specification of W thus defines a propeller parameter T/P. The flight velocity V can be found from Figure 1 if the propulsive efficiency is assumed (a transmission efficiency of 1.0 has been assumed in this discussion) and the required thrust/hp is given in Figure 2. For example, a 500 lb aeroplane must have a propeller thrust/hp of 16.4.

Eq. (3) may be interpreted as the inverse of C_L required for minimum power level flight, and it is apparent that the values of C_{D_f} and K quoted above infer a wing lift coefficient ($C_L = 1.73$) which is beyond the capabilities of most conventional aerofoils. It is also doubtful whether the use of the simple parabolic drag polar is justified under such conditions. While the lift coefficients so derived are clearly impractical without some form of high lift device, the values of C_{D_f} and K are representative of high performance light aircraft[11], and therefore have been used as a basis of the performance calculations of the hypothetical man-powered aircraft.

It is not the intention in this article to discuss the various aspects of high lift generation with or without boundary layer control, but reference should be made to a publication by Templin[12] in which the power requirements of aircraft having integrated lifting and thrusting systems are described. The optimum aeroplane for low speed flight is similar to the familiar flying jeep, with the important difference that optimum amounts of wing lift are employed to reduce the power requirements without resorting to high lift devices. The configuration of such an aircraft is unconventional; the wings are of low aspect ratio, and propellers or fans of large diameter are used in both the lifting and thrusting role. The low disc loading of the propulsion system however requires the smallest installed power/unit aircraft weight.

Ideal propeller performance

The ideal propulsive system is one in which there are no viscous losses; the physical propeller is replaced by an actuator disc, in which the only induced loss occurs as a result of axial motion of the fluid in the slipstream.

The thrust, power and slipstream kinetic energy are written as follows:

$$T = \rho\, u\, A(u_1 - V) \tag{4}$$

$$P = TV + E = \frac{\rho\, u\, A}{1100}\,(u_1^2 - V^2) \tag{5}$$

$$E = \frac{\rho\, u\, A}{1100}\,(u_1 - V)^2 \tag{6}$$

Ideal propulsive efficiency η is defined as the ratio of useful work (TV) to the total power.

$$\eta = \frac{TV}{TV + E} \tag{7}$$

Figure 3 shows propeller thrust/hp plotted against flight speed for various values of propeller disc loading T/A. Lines of ideal propulsive efficiency appear also as dashed. It is noted that the highest efficiencies occur at the lowest disc loadings regardless of flight speed.

If disc loading and propeller thrust/hp are specified, then the flight velocity and ideal efficiency may be found; in the example previously cited the 500 lb aeroplane is represented as a horizontal line at 16.4 lb/bhp on Figure 3. The flight speed and maximum possible efficiency for a representative disc loading of 0.5 lb/ft² are 29.2 and 0.85, respectively. A 400 lb aeroplane requires a lower value of T/P, hence a higher flight speed and ideal efficiency.

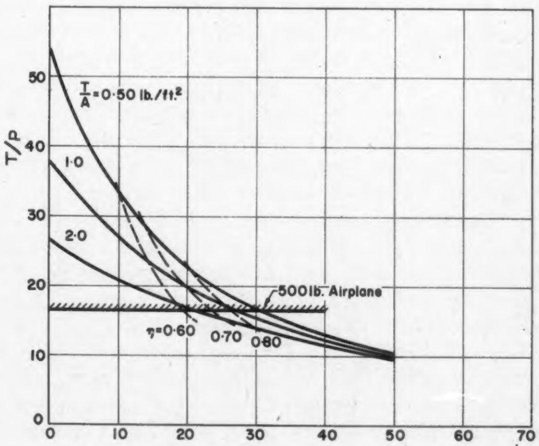


Figure 3
Ideal propeller performance

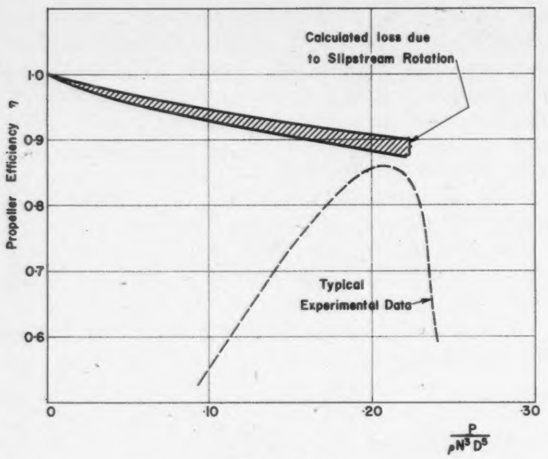


Figure 4
Propeller efficiency—effects of slipstream rotation
$V/ND = 1.0$

DEPARTURES FROM THE IDEALIZED ACTUATOR DISC

The ideal propulsive efficiency represents the highest attainable with a propeller of disc area A, absorbing power P at the speed V. The values quoted thus far will be affected in practice by losses due to friction, slipstream rotation and other induced flows in the slipstream; however, they may be used as a basis of comparison. The power coefficient C_p may be introduced to account for the effects of advance ratio, and a theoretical relation between C_p and ideal efficiency is written as follows:

$$C_p = \frac{P}{\rho\, N^3\, D^5} = \frac{\pi\, J^3}{2}\left(\frac{1-\eta}{\eta^3}\right) \tag{8}$$

Figure 4 shows the effects of power coefficient C_p on ideal efficiency; experimental data indicate the maximum level attained in practice[13].

Slipstream rotation

The power requirements of the propeller discussed thus far arise from the increase in axial kinetic energy of the final wake. In general, however, even for a frictionless propeller, the flow in the slipstream will also have both tangential and radial components due to the trailing vortex system. The latter (radial) components give rise to tip losses, which will be discussed in the ensuing paragraphs. The rotational motion is imparted by the torque reaction and can be significant. The resulting increase in angular momentum does not contribute to the useful work (TV) and hence represents a loss in efficiency.

The effects of slipstream rotation on propulsive efficiency are shown in Figure 4, where η is plotted against power coefficient. The shaded area is from the theory of Reference (14); each curve represents an envelope of many fixed pitch propellers, or one propeller of variable pitch. Data consistent with current practice are also shown as the dashed curve. The optimum value of C_p indicates a total loss of efficiency of 4% compared with the ideal propeller. The theory indicates that approximately half of this is due to slipstream rotation. Experience has also shown that the fixed pitch propeller, operating at very low advance ratios, or at zero advance ratio, suffers much higher rotational losses.

The additional loss of power due to slipstream rotation is relatively small under normal (i.e. cruising) operating conditions, but it exerts an important influence on the best distribution of induced velocities at the propeller disc.

Tip losses

In principle, the rotating propeller blade is similar to the finite aeroplane wing in that a sheet of vorticity of variable strength is shed along the span. The strength of this vorticity varies in an asymmetric manner across the radius, reaching maxima at root and tip; its distribution depends upon the number of blades and the condition that the propeller is "optimum". Unlike the wing vortex sheet which is usually considered planar, possessing a small velocity normal to the flight direction, that from a propeller blade is helical in form and moves axially downstream with a small relative velocity. The fluid velocities induced relative to this sheet (or sheets) are radial, tangential and axial in sense, and account for all of the induced losses. The radial motion gives rise to a loss of thrust at the blade tip. This loss is known as the tip loss, and varies inversely as the number of blades.

Reference (15) presents a theoretical analysis of the properties of the trailing vortex system of propellers having minimum induced losses; variations of this method are also used as a basis of design. A simple method for estimating this loss of efficiency is given in Reference (14).

Profile drag

The efficiency losses discussed thus far have been termed "induced" in that they are associated with the trailing vortex system. It may be shown that these losses are relatively small under favourable operating conditions. The blade elements are, however, also subject to external forces due to the viscosity of the fluid. The resulting effects due to profile drag can be and frequently are severe. In addition to the direct losses due to friction, it has been suggested[14, 16, 17] that there may be significant changes in the optimum shape of the loading curve, although this latter effect is usually ignored in practice (provided that the blade elements are operating at minimum profile drag).

Reference (17) points out the analogy between the wing of maximum lift/drag ratio in which the induced and profile drags are equal and the propeller of maximum efficiency, having a similar division between profile and induced loss.

The profile losses become particularly significant for propellers operating at low Reynolds numbers, as would be the case for model propellers or those for man-powered aircraft. A further discussion of the effects of scale are given in a subsequent section of this article.

PROPELLER SELECTION AND PERFORMANCE ESTIMATION

This section describes the effects of varying advance ratio, solidity and number of blades on optimum propeller efficiency and design power coefficient. The flight conditions are for the cruise, and the method of analysis is taken from Reference (18). The effects of

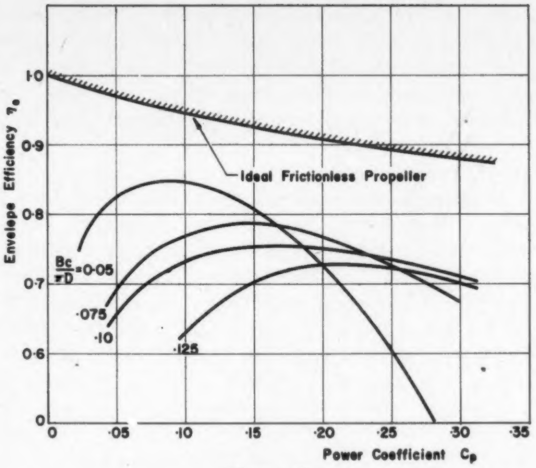


Figure 5
Calculated envelope efficiencies for a 3-bladed propeller (Clark Y profile), $V/ND = 1.0$

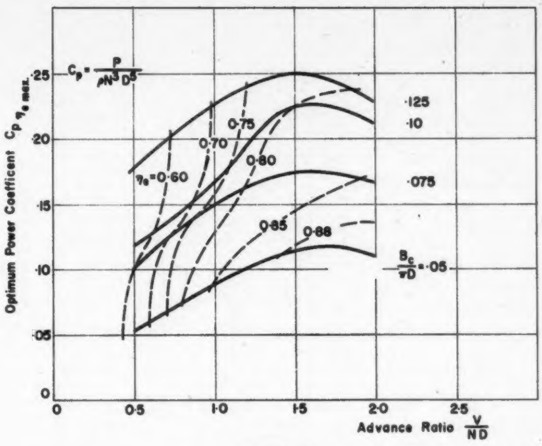


Figure 6
Power coefficient for maximum envelope efficiency (3 blades, Clark Y profile)

profile and induced loss are included in this comparison; propeller polars ($\bar{C}_L$ vs $\bar{C}_D$) inferred from many test results were considered the most reliable data to be used with the "single radius" method with which the above reference deals. Differences between this simplified performance method and a more elaborate strip theory calculation do exist, as pointed out by Reference (19); for example, the effects of planform or effective solidity (activity factor) and/or pitch distribution can only be demonstrated by the more elaborate methods. Nevertheless, for initial design studies, such as are presented here, especially in view of the uncertain effects of scale, the simple method shows the effect of changing the principal parameters.

Calculations were performed for a range of design advance ratio J, propeller solidity σ and number of blades B. The resulting curves (η vs C_p) are the loci of maximum efficiency for propellers of varying pitch. They are designated η_e. A Clark Y aerofoil section was used in the calculations. Figure 5 shows, for a 3-bladed propeller, curves of this type for $Bc/\pi D$ varying from 0.05 to 0.125.

Optimum values of η_e occur at values of C_p which increase with solidity. For the advance ratio shown ($J = 1.0$), $\eta_{e\,max}$ decreases significantly with $Bc/\pi D$. The ideal efficiency given by Eq. (8) is also shown as a basis for comparison.

Similar calculations were performed for design advance ratios of 0.5, 1.5, 2.0 and 2.5, and for propellers having 4 and 5 blades.

A convenient way to summarize the results for a given number of blades is shown in Figure 6 (for 3 blades). In this graph the power coefficient for optimum η_e is plotted against design advance ratio V/ND, and for various values of $Bc/\pi D$ (the activity factor is not specified, but all the blades are assumed to have a standard shape). Contours of $\eta_{e\,max}$ are shown. The maximum efficiency in this case appears to have a value of 0.88 or greater for a design advance ratio lying between 1.5 and 2.0, and a solidity[b] of 0.10. Similar calculations carried out for propellers having 4 and 5 blades indicated no significant differences in the highest value of $\eta_{e\,max}$ attainable. However, Figure 7 summarizes the effects of blade number and solidity on the choice of design advance ratio.

Frequently, propeller configurations must be chosen on some other basis than optimum cruising efficiency. For example, if a high solidity is selected (for high static thrust), then the design V/ND will be lower than that which gives the optimum cruise efficiency, implying also a slight change in $\eta_{e\,max}$. For example, for the 4-bladed propeller in Figure 7, the optimum V/ND is approximately 2.05, and $\eta_{e\,max}$ was estimated to be 0.88 for a solidity of 0.10. Selecting a solidity of 0.25 decreases the optimum V/ND to 1.40 and $\eta_{e\,max}$ to 0.78 approximately. It is noted that the performance may be increased slightly by changing the number of blades while leaving the total solidity constant.

The data presented in this section are to be considered as estimates only; the simple method used is probably accurate only for full-scale propellers of standard configuration, flying at high cruising speeds. The relatively high values of efficiency quoted here are affected in practice by the installation, scale, and other effects which are largely unpredictable by so

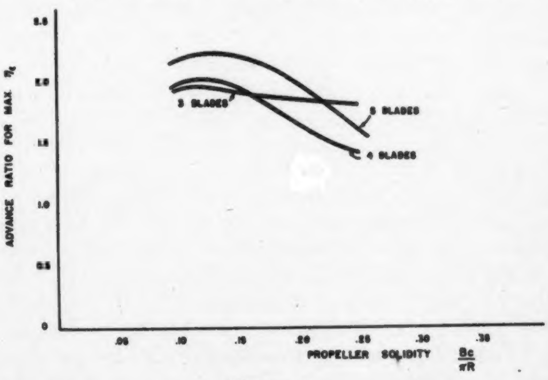
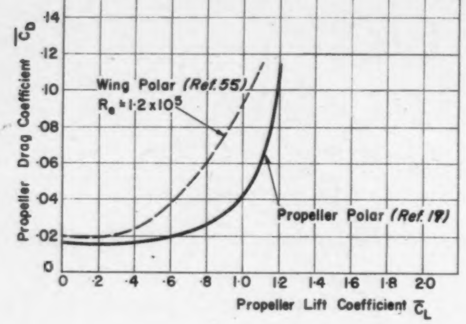


Figure 7
Effect of number of blades on design advance ratio and maximum efficiency

[b]Solidity is defined in the List of Symbols as $2Bc/\pi D$.



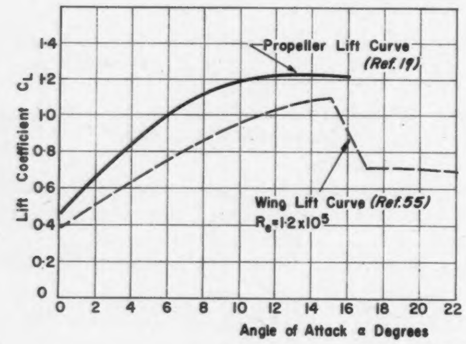


Figure 8
Comparison of wing and propeller characteristics—Clark Y profile

simple a theory. For example, the low solidities dictated by the requirements of high propulsive efficiencies may, when applied to the design of very low powered propellers, result in a narrow chord, giving rise to severe scale effects[19].

FACTORS AFFECTING PROPELLER PERFORMANCE —EXPERIMENTAL DATA

Propeller polar

The calculations presented in the previous section showed how propeller efficiency is affected by changes in some of the important aerodynamic parameters. The theory was crude; however, it was possible to account for such real fluid effects as profile drag, to the extent that the lift/drag characteristics of the whole propeller were considered to apply at a representative spanwise station (usually taken as $r/R = 0.7$). These propeller characteristics are similar in some respects to those of the aerofoil at that station.

Data inferred from many tests of full-scale and model propellers may be synthesized to form a drag polar for the propeller. Reference (19) describes the results of such tests, and Figure 8 shows, for the Clark Y section, differences between the synthesized polar, and that of a wing of aspect ratio six. The propeller polar includes the effects of induced as well as profile drag, and therefore cannot be compared with the two dimensional aerofoil polar at $r/R = 0.7$, except under conditions of zero lift (thrust).

The concept of a propeller polar is useful not only for calculating performance, but also in assessing the relative merits of propellers having minor modifications; it has also been used to illustrate the effects of geometry[20, 21, 22], scale and compressibility. For example, Reference (19) shows how the "clean" propeller polar is affected by the addition of root fairings. Similarly, many other modifications, some of which are discussed in the following sections, may be compared using the propeller polar.

Effect of profile section

A series of full-scale tests was conducted by the NACA[23] in order to compare two conventional propeller sections (RAF6 and Clark Y) with other sections having rather extreme characteristics as regards camber. All propellers tested were 10 ft in diameter, had 3 blades, and were identical in planform. Details of the propeller sections are given in the above reference and noted on Figure 9.

The chief difference between the aerofoils is the amount of camber or design lift coefficient, although there are slight differences in the thickness form curves. The effect of increasing camber on aerofoils is to increase $C_{L_{max}}$ and C_{D_o}. Propeller performance will reflect this characteristic in that the envelope efficiency will depend directly upon C_{D_o}, while the static thrust will depend on $C_{L_{max}}$. Some of the adverse effects of high camber may be overcome by the use of laminar aerofoils; their application to propellers will be discussed further on.

Figure 9 shows the propeller polars inferred from test data for the various propellers. The locus of maximum propulsive efficiency is also indicated. A legend summarizes the pertinent profile characteristics. At high values of $\bar{C}_L$ (> 1.0), the drag coefficients do not reflect the effects of camber previously stated; the more highly cambered profiles having the lowest $\bar{C}_D$ and vice versa. In this case, particularly in view of the low propulsive efficiencies, the blades were probably stalled. At lower values of $\bar{C}_L$, however, (corresponding to the highest η_e) the RAF6 section had the highest drag and the NACA $2R_200$, having a lower camber, the lowest.

The influence of blade drag on maximum envelope efficiency at low values of $\bar{C}_L$ (close to $\eta_{e\ max}$) is shown in Figure 10, also taken from Reference (23). The effect of large changes of propeller drag coefficient (approximately C_{D_o}) on $\eta_{e\ max}$ is low and indicates an upper limit to the possibilities of improving $\eta_{e\ max}$ by these means. The theoretical ideal efficiency for zero drag is noted to be only slightly higher than that extrapolated from the curve.

A conclusion of the above reference (which may be applied to the propeller selection of man-powered aircraft) is that at the design condition (cruise) the aerofoil selection should be made on the basis of C_{D_o} only. This will generally compromise the takeoff and low speed characteristics; Figure 5 of Reference (24) indicates that the spectrum of camber required for efficient propeller operation varies widely from high to low values for takeoff and cruise, respectively.

Minor differences in propeller performance may be had by varying both maximum thickness and nose radius of the profiles. The effect of an increase in thickness on propellers with Clark Y and RAF6 sections is discussed in Reference (25). A slight increase of efficiency was noted with the thickened Clark Y;

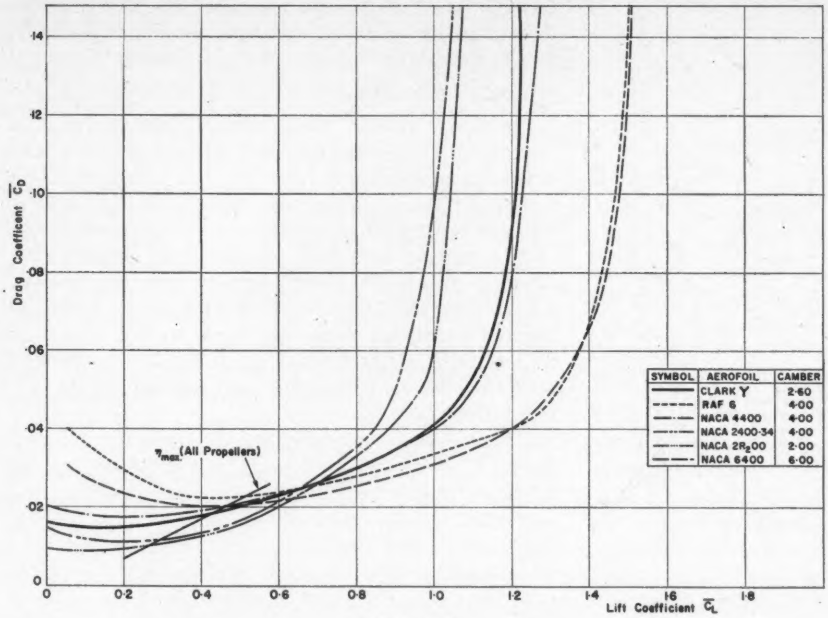


Figure 9
Propeller polars illustrating the effect of camber on performance

formance, the advantages of a cambered laminar flow propeller section become clear. The compromise between takeoff and cruise requirements may also be relieved. Qwick in Reference (29) discusses this and other propeller problems further. Reference (30) indicates that laminarization of the pressure side of a ducted fan blade by means of a slot provides a sizeable increase in efficiency.

Effect of blade number and solidity

Theory indicates that the effects of activity factor (effective solidity) and blade number at a given design condition tend to cancel each other. An increase of solidity at constant power coefficient or advance ratio increases the loading per unit disc area and hence the induced loss; the efficiency therefore will decrease. An increase in the number of blades at constant solidity reduces the tip loss, resulting in more thrust for a given power.

however the RAF6 exhibited an opposite effect, attributed, in part, to the increased effective camber, and a probable resultant stall.

The effects of leading edge imperfections are also important. Reference (26) describes an experiment in which the leading edge of a conventional high speed section was deliberately flattened over most of the span of the propeller. The resultant loss in efficiency at low tip speeds was attributed in part to separation at the leading edge. The effect of leading edge imperfections on thick (21%) symmetrical aerofoil sections, such as those which may be found on the inboard sections of a propeller, may be inferred from the results of data presented in Reference (27). Hollows and ridges having a maximum amplitude of the order of 0.15% chord were scribed near the leading edge of the aerofoil. They appear to have a significant effect on the performance of a windmill model; the presence of these irregularities decreases both maximum torque and total drag, reflecting the effects of roughness on $C_{L_{max}}$. An attempt at "laminarization" is described in Reference (28); polars for similar propellers having different profiles are described. Clark Y and RAF6 profiled propellers are compared with one having a laminar flow section of high mean camber. The profile is not specified but it is similar in some respects to the NACA series 16, a well-known laminar flow propeller section. The camber was 4.5%. The polar of the laminar propeller for subsonic tip speeds indicated a lower $\overline{C}_D$ at design conditions than either the Clark Y or the RAF6 propellers. At high mean lift coefficients (takeoff), it was still superior to the Clark Y. Although the value of the mean blade drag coefficient for maximum efficiency is not necessarily $\overline{C}_{D\,min}$ (see Figure 9), it nevertheless tends to this value for the more highly cambered blade sections. Therefore, using $\overline{C}_{D\,min}$ as a basis of comparison of per-

Reference (31) reports a series of tests in which the efficiencies of propellers having 2, 3 and 4 blades were compared. The planform and section profiles of these propellers are identical. A propeller having a larger blade area corresponding to a 50% increase in mean blade width was also tested, and it was therefore possible to assess separately the individual effects of

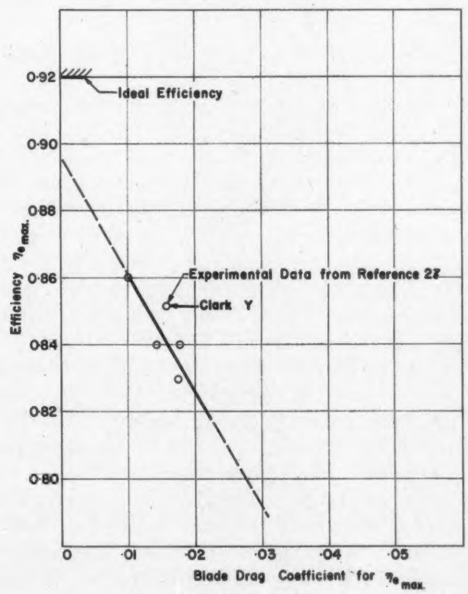


Figure 10
Effect of propeller drag coefficient on maximum propulsive efficiency

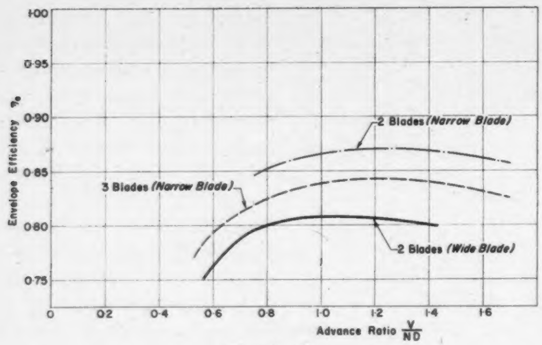


Figure 11
Envelope efficiencies illustrating the effects of solidity and number of blades (RAF6 profile)

solidity and number of blades. Figure 11 summarizes these tests, showing the effect of number of blades on propellers of constant solidity. It is seen that changing from 2 to 3 blades results (approximately) in a 3% change in efficiency. The solid curve, well below the others, illustrates the effect of solidity; a 50% change in blade width for a 2-bladed propeller results in a 5% decrease in efficiency. It is noted from calculation (Figure 5) that the maximum or envelope efficiencies occur for lower design advance ratios with blades of high solidity. A similar effect is noticed between propellers of reduced numbers of blades at constant solidity.

Effect of blade width distribution

It has been shown previously and discussed in Reference (31) that changes in propeller effective solidity (i.e. activity factor) have significant effects upon the envelope efficiencies. In these tests no mention was made of the effect of a change in blade width distribution which occurred in one comparison; the wide blade noted in Figure 11 actually had considerable blade area concentrated toward the inboard sections.

Certain marked differences in constant speed efficiency (i.e. η_e vs V/ND for fixed C_p) of a series of model propellers of differing blade width distributions were noted in Reference (32). The models were designed to have identical effective solidities and therefore envelope efficiencies. Representative blade width distributions are those shown in Figure 12. It was found that their constant speed efficiency curves were significantly different at advance ratios well below those at which maximum efficiency occurs. This is shown for the three blade shapes in Figure 12 and for constant power coefficient $C_p = 0.50$.

The more efficient operation of blade I (tapered from root to tip) as the advance ratio decreases is ascribed to the redistribution of loading from the less efficient, stalled, outboard sections to the unstalled inboard sections, thereby converting the power more efficiently into thrust. The effect of a decrease in C_p is to reduce the spread between the tapered and untapered blades. (The planform effects discussed here do not appear to any marked degree as maximum envelope efficiency is approached.)

The desirability of operating the propeller of the man-powered aircraft at constant C_p throughout the takeoff or landing may be offset by the practical difficulties of variable pitch and the advantages of a purely mechanical takeoff (e.g. pedalling).

PROPELLER BOUNDARY LAYER AND SCALE EFFECT

In many respects the propeller blade is similar to a finite rotating wing, and most theoretical treatments of the problem separate the induced effects from the viscous effects. In doing this, two-dimensional section data are often used to calculate thrust and total power. Comparisons of calculated and measured propeller coefficients at low Reynolds numbers, however, reveal a wide discrepancy even when the appropriate Reynolds number correction is applied to the section data. This is generally attributed to the effects of centrifugal action on the growth, profile and stability of the propeller boundary layer.

While little work has been done on the complex nature of the propeller boundary layer, many experimenters have investigated, both experimentally and theoretically, the boundary layer flow of a rotating disc, and in one case[33] have attempted by means of flow visualization to correlate results with the observed flow on a propeller blade. Reference 34 covers most of the aspects of the flow on rotating discs, applying the results to the calculation of boundary layer profiles on an infinite rotating wing.

Observation has shown that the disc acts as a centrifugal fan with regard to the secondary flow on its surface. The boundary layer fluid is expelled almost tangentially at the edges of the disc, while the fluid outside, at constant total pressure, experiences high induced velocities near the axis of rotation. The boundary layer streamlines are of spiral form. Flow visualization[35] and measurement of local skin friction coefficients[36] indicate a laminar region on the inner portion of the disc, with a well-defined transition to turbulence on the outer region. Measurement of transition Reynolds numbers ($r^2\Omega/\nu = 300{,}000$) indicate that the onset of turbulence is accelerated on rotating bodies of this type.

Visualization of the boundary layer flow on both suction and pressure sides of a marine-type propeller are discussed in Reference (33). In this experiment, which was in water, dye issued from small holes near the leading edges of the blades, thus moving with, but

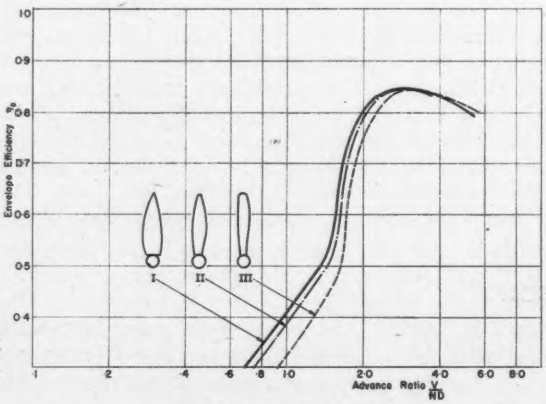


Figure 12
Effect of blade shape on constant-speed efficiency

not disturbing the boundary layer flow. Laminar conditions on the suction side were identified by a fan-like area of coloured fluid, extending from the orifice in a chordwise and spanwise sense. Areas of turbulent flow were characterized by the appearance of a narrow, highly irregular streak of dye.

From the data presented in this report, it is evident that the turbulent area of the blade is dependent upon both Reynolds number and propeller loading. Figure 13 shows the outer limits of observed laminar flow on the suction surface of a typical marine propeller blade for two propeller thrust coefficients. It is seen that the blade is mostly turbulent at the lower thrust coefficient. The pressure side however (not shown here) exhibited almost complete laminar flow under the same operating conditions.

A significant comparison was made by the author of the above reference[38] between rising thrust and torque values (at constant V/ND) and an increasing area of turbulence on the suction surface. Agreement between measured thrust and torque values and those calculated using two-dimensional section data was poor; this was attributed to the premature spread of turbulence via the radially-directed boundary layer flow.

Similar measurements on conventional propellers in air are scarce. Chordwise and spanwise static pressure measurements, as well as wool-tuft visualization of the boundary layer, are described in Reference (37) for a blade of a small-scale ducted fan. Similar measurements of static pressure have been made by the NACA on aerofoil sections of a full-scale single-bladed propeller[38].

The most striking result noted in the above reference[37] was the tendency for the blade sections to resist the stall. Both $C_{L\,max}$ and $dC_L/d\alpha$ at all stations along the blade were noticeably higher than those of the basic two-dimensional aerofoil, particularly close to the root. The stall resistance was attributed to the thinning of the boundary layer, and a parallel was drawn with boundary layer suction. The variation of $C_{L\,max}$ with radius is shown in Figure 14 for the ducted fan and propeller; section values of $C_{L\,max}$ based on local (chordwise) Reynolds number are also plotted, illustrating the effects of rotation. Further evidence of the centrifugal effects is reflected in the wide varia-

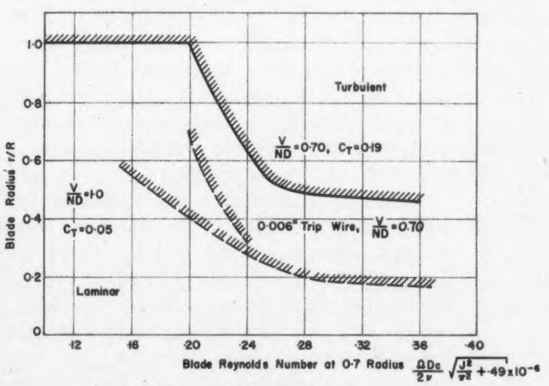


Figure 13
Limits of observed laminar flow on a rotating propeller blade

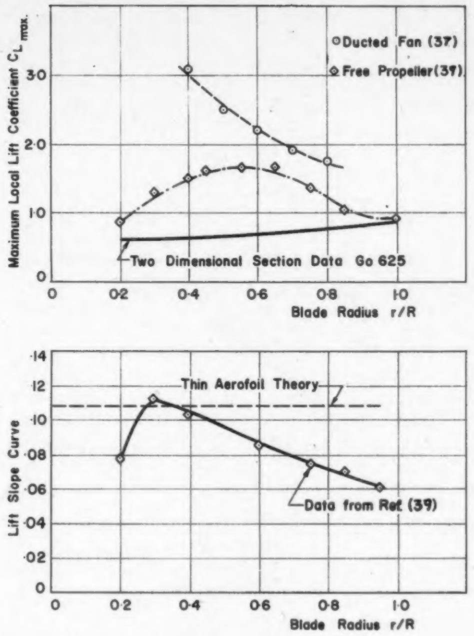


Figure 14
Radial variation of propeller section characteristics $C_{L\,max}$ and $dC_L/d\alpha$

tion of lift curve slope across a propeller radius, discussed in Reference (39) and also shown in Figure 14.

The effects of scale or Reynolds number on aerofoil sections and wings are well known; Reference (40) summarizes work done by the NACA on this subject, for a range of Reynolds numbers normally encountered during model tests. Very low values of this parameter ($< 60{,}000$) are likely to occur on some propeller sections for which data are both scarce and unreliable. Scale effects, however, can be severe. Reference (41) presents interesting measurements of the profile characteristics of model aeroplane wings. Figure 15 shows lift and drag curves for the Go 625, a typical high lift section. The lifting characteristics of the section below $Re = 100{,}000$ are seriously altered; large changes in lift curve slope and zero lift angle are evident.

The estimation of scale effect on propellers is not straightforward. Application of two-dimensional data, similar to that shown in Figure 15, to propeller blades leads to the conclusion that the blades are likely to stall along inboard sections and that drag coefficients will be high due to the very low Reynolds numbers. It has already been shown, however, that the inboard sections may be subjected to high local lift coefficients without stalling and that the lift curve slope increases rather than decreases as indicated in Figure 15. It has also been noted that the spread of turbulence over the blade is enhanced by the spanwise flow of the boundary layer, thereby reducing the drag coefficient[42].

Very few tests have been performed on propellers solely for the purpose of establishing scale effect. Those data which are available indicate a decrease in maximum propulsive efficiency with propeller diameter. A loss of 4% in efficiency was noted in Re-

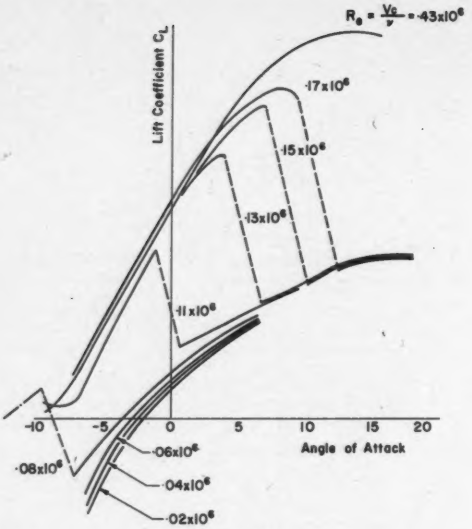


Figure 15
The effect of Reynolds number on lift characteristics of the Go 625 profile

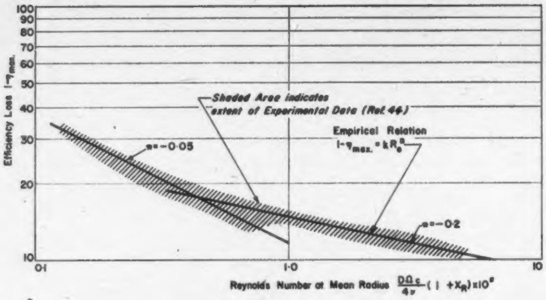


Figure 16
Variation with Reynolds number of maximum efficiency of a compressor stage

ference (19) for model propellers ranging from 4.5 to 2.5 ft in diameter. A similar loss of efficiency between model and full-scale propeller test results is indicated in Reference (43).

Extensive measurements have been made on the effects of Reynolds number on the performance of a single-stage axial compressor[44]. Efficiency loss is plotted against blade Reynolds number in Figure 16; the effects of very low Reynolds number on this type of rotor are severe.

Variations of static thrust effectiveness with tip speed for both model and full-scale propellers are reported by References (45) and (46), respectively, and have been attributed, in part, to Reynolds number effects.

Attempts have been made to assess the effects of artificially-induced turbulence on the characteristics of marine propellers. The use of leading edge trip wires or upstream turbulence screens in model tests was suggested in Reference (33) as a method of producing the effects of full-scale Reynolds numbers. This method proved to be successful in that the thrust coefficients at low Reynolds numbers attained the higher values associated with high Reynolds numbers. Torque coefficient, however, continued to rise due to the profile drag of the wire. In Reference (44) turbulence wires were employed to suppress the scatter from propeller test data and the coefficients of thrust and torque exhibited essentially the same result as noted in Reference (33). Figure 13 shows the limits of laminar flow on a propeller blade with an 0.006 inch leading edge trip wire.

Further references to scale effect on model propellers are included in References 47 to 55.

DISCUSSION — APPLICATION TO THE MAN-POWERED AIRCRAFT

It has been the purpose of the preceding sections to attempt to show the various aspects of design and operation of efficient propellers. The man-powered aircraft, as most people envisage it, approximates the conventional aeroplane with independent lifting and propulsive systems. The operation and design of propellers in this role are well understood, and hence this article has dealt with various factors affecting propulsive efficiency in the cruise.

From considerations of simple propeller theory, maximum efficiency is achieved with as low a disc loading as possible; this is illustrated by Figure 3. In practice, however, efficiency is limited by profile drag; increasing the propeller diameter indefinitely also implies an increase of the blade area, resulting in a more significant fraction of total power dissipated on viscous losses. A more realistic propeller selection for the crusing condition (Figure 5) has indicated a propeller solidity of 0.10 and a design advance ratio of 2.05. The optimum calculated efficiency was 0.88. Assuming an over-all efficiency of 0.8, the optimum flying speed of the 500 lb aeroplane would be 27.5 ft/sec, and the propeller tip speed would therefore be approximately 50 ft/sec.

Further optimization of power coefficient allows the calculation of maximum propeller diameter for a given number of blades. The effect of a change in the number of blades is less on maximum efficiency than it is on the best power coefficient; a 3-bladed propeller has a value of $C_{P_{\eta\ max}}$ of 0.115, compared with 0.190 for the 4-bladed propeller. The latter will, of course, result in the smallest propeller diameter (e.g. 5.50 ft).

The performance method described in Reference (18) does not allow for large variations in section Reynolds number; the test data available are usually representative of flight conditions, and the levels of Re are such that losses are a minimum. It has been shown, particularly in Figure 16 that blade Reynolds numbers as low as those implied by the above numbers will have a serious effect upon the maximum efficiency. For example, the section Reynolds number at mid-span of the 4-bladed propeller is approximately 0.03 million; the maximum efficiency from Figure 16 is 0.78. Some improvement may be had by employing the 3-bladed propeller, since mean chord is proportional to D/B. The larger diameter and fewer blades result in some 50% increase in Reynolds number, bringing the maximum efficiency up to 0.82.

Since decreases in propeller efficiency have a direct effect upon all-up weight for a given flying speed, efforts have been made in the past to investigate means

of reducing losses. The present state of propeller theory is such that most designers are confident of minimizing the induced losses. The correlation of maximum envelope efficiency with minimum propeller drag coefficient indicates that the proper choice of aerofoil section is important in reducing the profile loss. A section of small camber is usually desirable. Laminar flow sections have been in current use for many years, mostly in connection with problems of compressibility, but propeller experiments in Germany during World War II demonstrated that the adverse effects of camber (4.5%) on cruising performance were overcome by the use of a laminar flow section[30]. The advantages of the cambered aerofoil section also appear in increased static thrust for takeoff.

Other means of improving propeller performance are less subtle, and at present are of doubtful value. Qwick[29] has suggested employing the natural (centrifugal) convection currents which would occur in a hollow blade with an intake and exhaust at the root and tip sections, thus having suction and blowing boundary layer control respectively at these sections. The practicability of this scheme was questioned in Reference (28) due to the extremely low suction or blowing coefficients which could be realized. Moreover, it has already been shown (Figure 14) that considerable boundary layer control exists on the inboard blade sections.

The use of leading edge slots has also been suggested[29] as a means of improving the takeoff performance. This allows the inboard sections to operate without stalling; however, the penalty in cruising performance may be high. A more ingenious use of slots is in the suppression of transition from laminar to turbulent flow on the pressure side of a fan blade[30]. The sink effect of the slot is such that the boundary layer on 60% of the chord is removed, resulting in an extension of laminar flow. Sizeable increases in the efficiency of an axial flow blower were reported.

Some mention has already been made of the possibility of using the propeller for a man-powered aircraft in the lifting as well as thrusting configuration. While this article has not discussed the performance characteristics of such a scheme, it is probably worth while to point out some of the interesting features of the ducted propeller, which is of possible application. The increase of effectiveness due to the ducted propeller comes from two sources: first, the shroud or duct has the effect of endplating the propeller blades and so reduces the tip losses. A second source of thrust is due to the pressure distribution of the duct itself; simple theory indicates that a 26% gain in static thrust is available, over a similar free propeller absorbing the same power. This gain in thrust decreases rapidly with forward speed; the profile drag of the duct would further reduce the effectiveness of the ducted propeller, and it has not been seriously considered for the man-powered aircraft of the conventional form.

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ANNUAL GENERAL MEETING

The Annual General Meeting of the Institute will be held at the

SHERATON-MOUNT ROYAL HOTEL, MONTREAL

on the

14th and 15th June, 1962

The technical sessions will be associated with the theme of SAFETY and are tentatively planned as follows:

Methods of Accident Investigation and Engineering Considerations
(e.g. Investigation techniques, technical causes of accidents, safety provisions in the event of accidents)

Safety in Space Operations
(e.g. Destruction on malfunction, escape from space vehicles)

Operational Causes and Avoidance of Accidents
(e.g. Human factors, training, experience, flight authorization procedures, air traffic segregation)

Members of the C.A.I. are invited to present papers on any of the above-mentioned subjects and anyone wishing to do so should submit a brief summary for consideration by the National Programmes Committee. Such summaries must be in the hands of the Secretary by the 31st December, 1961.

REVIEW OF THE PAST, PRESENT AND FUTURE AIRCRAFT BRAKE†

by C. R. Weaver*

B. F. Goodrich Aviation Products

SUMMARY

The rapid advance of aircraft performance has necessitated an equal improvement in aircraft brakes. A short time ago, the heart of the aircraft brake was organic lining material used with a mild steel or cast iron heat sink in a form of disk or drum. Today, the brake designer has to meet much higher energy capacities and higher torque requirements while being asked to meet very limited weight and envelope specifications.

New metallic brake linings have been developed and used with special alloy steel disks. Today, the lining material joins the disk as a heat absorption member of the brake and both are able to withstand very high temperatures.

Considerable development is being done to improve service life and extend capacities of present brake designs. The liquid-cooled brake system under service test at the present time is an available method for accomplishing this. Other methods will require the use of new materials, such as beryllium, which are currently under development.

INTRODUCTION

The rapid advances made in aircraft performance have necessitated equally rapid improvement in the various aircraft components. Aircraft brakes, though often overlooked, play a very important part in the over-all mission of today's aircraft. High performance in flight generally produces high landing speed characteristics requiring dependable high-capacity brakes so the current air fields can be used.

Auxiliary braking methods, such as drag chutes, reverse thrust, and landing field arrestor systems, are also employed in some cases. These systems all have some limitations; therefore, they assist but do not replace wheel brakes.

PAST BRAKE EQUIPMENT

In the late 1920's the aircraft tail skid was replaced with the tail wheel. As the skid was a very effective brake, the use of the tail wheel forced the consideration of some type of wheel brakes. The shoe-type drum brake proved to be effective.

One of the last and largest aircraft to use the shoe type brake was the Douglas DC-3. This aircraft had two main landing gear wheels with two brakes per wheel. Each brake was designed to handle a kinetic energy of 1,605,000 ft lb.

The basic friction components in these early shoe brakes were a soft organic lining material and a drum of mild steel. The shoe brake covers only part of the drum circle and usually has a relatively uneven wear pattern. This, of course, leads to short service life.

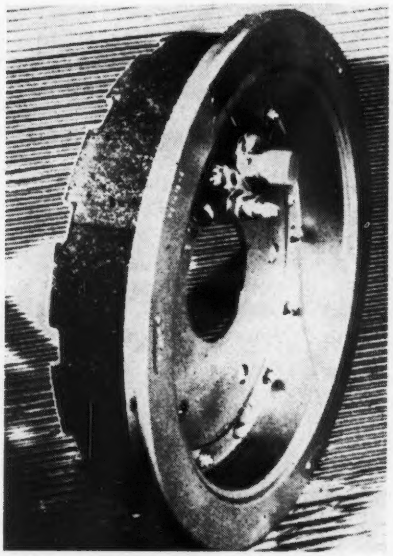

Figure 1
Expander tube type drum brake for Douglas DC-3

The expander tube drum brake was developed to overcome the limitations of shoe brakes. This brake was made up of a full circle of lining blocks, actuated radially by an expander tube. Two stamped steel side frames, when bolted together, formed the support for the tube and also provided the lugs for transmission of the torque from the lining blocks. The full circle of lining blocks provided more even surface contact as well as a greater surface area. These factors combined to give a brake of longer service life, higher torque capability, and greater kinetic energy capacity. As an example, this brake designed to fit the drum of the DC-3 (Figure 1) at no increase in weight produced approximately 30% more braking ability.

The single main wheel landing gear continued in general use for larger aircraft, particularly in the military field. Increase in aircraft weight and size brought an increase in wheel size. Large wheels, of course, offered a larger diameter in which to put a brake assembly. This was a natural environment for the expander tube drum brake, which was very successful

†Paper read at the Mid-season Meeting of the C.A.I. in Winnipeg on the 27th February, 1961.
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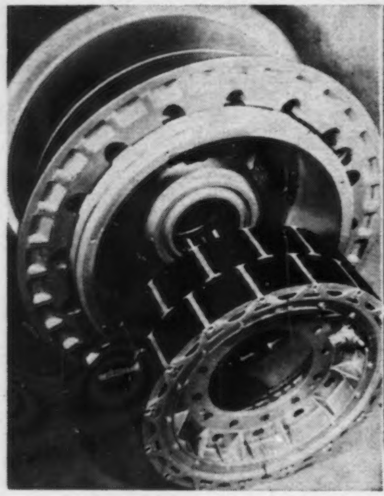


Figure 2
Wheel and duplex expander tube brake for rear gear of Boeing B-47

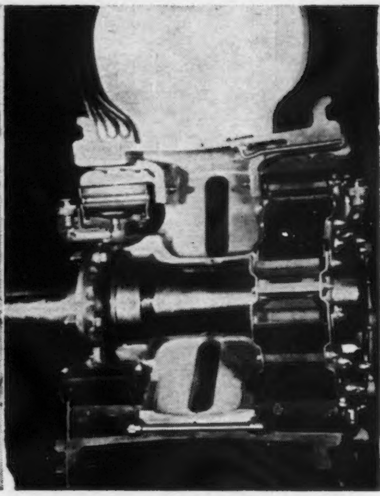


Figure 3
Cutaway of wheel and dual expander tube brakes for Lockheed 1049C

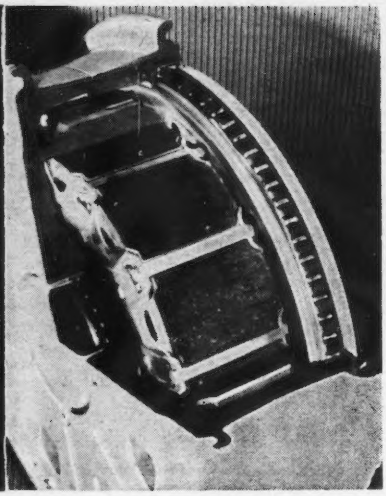


Figure 4
Wheel and internal expander tube brake cutaway for Republic RF-84F

on such aircraft as the Boeing B-17, B-377, and B-47 (Figure 2). In these typical installations, the drum was usually a steel shell with a cast-iron liner. This, in conjunction with improved organic lining materials, produced the necessary torque and kinetic energy capacity. These brakes provided the lightest weight, least expensive equipment, and gave excellent service life.

Disk brakes were also being developed. They came into general use on aircraft using multiple and/or small-diameter main wheels as typified by the Lockheed T-33 and Convair 240. The disk brake combined the advantage of being able to put more energy and torque into a very small package with its low displacement requirement, making it ideal for the master cylinder operation in the smaller aircraft. Of the many approaches to disk brake design, two principal ones emerged. First was the multiple disk brake and the second, the single disk spot brake.

The multiple disk unit was usually made up of several thin rotating disks alternating with thin stationary lining carriers, mounting a series of spots of organic lining material. Although the multiple disk brake packed a considerable amount of kinetic energy into a small package, its chief disadvantage was the large number of parts and the inherent higher cost of maintenance and manufacture.

The single disk spot brake had one fairly heavy disk. One or more spots of lining were used, depending on the torque and KE requirements. Each spot was attached to the actuation piston while a companion piece of material was attached to the anvil of the brake housing. As the single disk rotated between the two sets of linings, the clamping action produced the braking torque. Because of the small surface area of lining material available, the spot brake generally had high lining area loadings and relatively short service life. However, ease of maintenance and overhaul compensated for this to some degree.

The two types of disk brakes, as well as expander tube drum brake, continued to be developed. However, the trend away from the single main landing gear on the large aircraft to the T-type gear using multiple smaller main wheels reduced the space available for brakes. The result was that the last of the larger aircraft on which the drum and disk brakes competed directly were typified by the Convair 340, Douglas DC-6B, and Lockheed 1049C (Figure 3).

Table 1 is a brief listing of some of the aircraft from the DC-3 to the Lockheed 1049C. It shows the trend in KE/wheel, wheel bead diameters, and heat-sink loadings (KE/lb of HS) for brakes using organic linings.

The progress of brake capability indicated by the figures in Table 1 was a result of primarily improving the friction components of the brake. Taking the lining material first, it started with the very soft organic materials which withstood temperatures up to approximately 700°F. This asbestos-phenolic based lining was further improved by the addition of friction modifiers, such as graphite, alumina, and ceramics and metallic chips, until it withstood temperatures of approximately 1200°F. Of course, the harder and more abrasive linings produced both wear and temperature problems for the disks and drums. Whereas the organic lining's chief job was to develop friction, the disk or drum's job was to absorb and store the heat developed by the conversion of kinetic energy. In addition, the disk and drum had to resist the wear of the lining material.

The early drums were mild steel. As energies were increased the centrifuse drum, having a steel shell and cast-iron liner, was used. It had very good heat absorption characteristics as well as stability at the increased temperatures. The use of the very hard abrasive organic linings and the further increase in energy inputs developed the need for special alloy steel drums. The final step in drum design was the use of an alloy steel, Timken 1722AS. Aircraft such as the Republic RF84F (Figure 4) and Boeing B-52A use brake drums of this material.

TABLE 1

Aircraft	Type	Wheel Size	Bead Seat Dia-In	KE/Wheel Ft Lb	Brake Weight-Lb	Heat Sink Weight-Lb	KE/Lb of Heat Sink	Lining Material
Douglas DC-3	Transport	17.00-16	16	3.2×10^6	58.8	31.3	102,500	Organic
Boeing B-377	Transport	56" SC	27	22.1×10^6	168.0	96.0	230,000	Organic
Boeing B-47	Bomber	56 x 16	28	24.3×10^6	205.5	132.5	183,500	Organic
Republic RF-84F	Fighter	32 x 6.6	20	16.2×10^6	96.5	52.0	311,500	Organic
Lockheed L-1049C	Transport	17.00-20	20	23.0×10^6	208.0	90,0	255,500	Organic
Convair 340	Transport	12.50-16	16	7.7×10^6	49.0	30.5	252,500	Organic

The early disks were also of mild steels and, for the same reasons as the drums, required improvement. They progressed through the 4130 heat-treated steels to the use of the Timken alloy 1722AS. By the improvement of the disk as well as of the drum material, we have raised their maximum operating temperatures from approximately 1000°F to over 2000°F.

The practical temperature limits of both the organic linings and the disk and drum materials had been reached. As the capacity of a brake is controlled by the high temperature limit and mass of the friction materials, a new approach to the aircraft brake problems was needed.

The North American F-100, Douglas DC-7C and Lockheed 1649 were typical new aircraft designs of this time period. Space and weight for brakes was limited while the energy and torque requirements had increased. To meet these new requirements a multi-disk brake design was used in combination with the newly developed metallic linings. These new linings operated at much higher temperatures than did the organic linings. Also, being metallic, they joined the disk as part of the brake heat-absorbing mass. The result was that more kinetic energy could be handled per pound of brake; thus, more compact brake design.

The early metallic linings were basically sintered bronze or iron with friction modifiers such as ceramics, graphite, and alumina. They developed high static and moderate dynamic coefficients of friction. However, they tended to produce grabbing or chatter during low aircraft speed brake applications. These metallic linings had a maximum operating temperature of approximately 1500°F.

The high temperature metallic linings used with equally high temperature disks did bring on some problems with the hydraulic actuation seals in the brake. However, the use of insulating materials on the ends of the actuation pistons, and between the piston housing and the heat sink, reduced or eliminated seal problems resulting from brake heat.

We have briefly covered the development of the aircraft brake up to the present time. Now, in considering brake design for current aircraft, we will separate the military and commercial equipment. This is necessary as the design approaches can be quite different.

COMMERCIAL BRAKE DESIGN

Commercial aircraft are either directly or indirectly used in profit making. This dictates a cost-conscious, conservative approach to the design of brake equipment. Therefore, conventional brake designs (Figure 5) are a *must*. By the conventional brake design we mean a brake assembly that is attached to an axle torque flange next to the strut or bogie beam. The stationary parts of the heat sink are keyed to the brake torque plate, while the rotating members are keyed to the wheel mounted on an axle outboard of the brake assembly. With this approach to design, the piston housing or actuation member of the brake is usually slightly outboard of the wheel profile, while the heat-sink members are within the wheel contour. The brake designs for the Douglas DC-6B, Lockheed Electra (Figure 5) and Boeing 707 are typical of this design approach.

The commercial field covers a wide range of airplanes, from the Pipers and De Havilland's to the Boeing 707's and Douglas DC-8's. Therefore, we will separate the light aircraft brake equipment from the heavier transport brake equipment, for ease of brake description.

Light aircraft brakes

The lighter aircraft have for many years used a single disk spot brake with good success. However, these aircraft like all others have grown in size, weight, and horsepower, which increased the brake torque and kinetic energy requirements. The simplicity and low

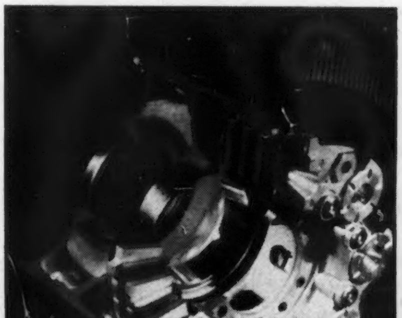


Figure 5
Cutaway of wheel and disk brake for Lockheed Electra

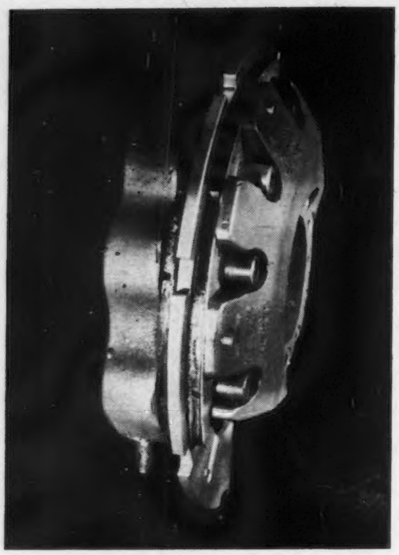


Figure 6
Single disk pad brake for De Havilland Caribou

weight of the single disk brake make it desirable to retain its basic features in new designs.

When the organic lining was used it was attached directly to the actuation piston. This method gave support to the lining material and insulated the piston, but limited the lining area. Now, to meet new brake requirements without increasing the brake envelope, improved materials were needed. Recent developments in the sintered iron lining have produced a smooth chatter-free material acceptable for light plane use. The new lining also develops good coefficients of friction over a wide temperature range. As the sintered material is backed with steel, larger lining segments (Figure 6) can be used without direct piston support. The use of metallic linings requires that the pistons be insulated to prevent brake heat from damaging the hydraulic seals. The new sintered iron lining materials have raised the KE and torque capabilities of the single disk brake while reducing fade and improving service life.

Latter versions of the De Havilland Caribou (Figure 6) will have improved braking capabilities owing to the use of the above materials in the brake design.

Transport aircraft brakes

We are presently designing brakes for transport aircraft using piston, propjet, and pure jet engines. The design approach is the same in all cases; however, the brake requirements for a jet aircraft are more severe in both certification tests and in service use. There are many conditions that go to make up the test and service requirements.

The jet aircraft is quite clean aerodynamically and lands at high speeds, while being required to use existing air fields. The minimum field length that a commercial jet is certified for is based on a takeoff run, at maximum gross weight, to a takeoff speed of V_1 and then a maximum effort brake stop. This stop is made without use of auxiliary braking devices such as reverse thrust. With the higher takeoff speeds of the jet aircraft combined with the short field requirement, the brake must develop high torques and decelerations. The common rejected takeoff (RTO) deceleration was 6 to 8 ft/sec^2. Now, some of the brake deceleration requirements of jets are 9 to 12 ft/sec^2.

The high deceleration rates are of course coupled with increased KE absorption requirements. For instance, the Lockheed 1049C had an RTO KE of 23,000,000 ft lb and the brake fitted into a 17.00-20 main wheel. Using this same size wheel, the Boeing 707 Intercontinental brake (Figure 7) is required to absorb an RTO KE of 44.5×10^6 ft lb. The total weight of the two brakes is about the same. Comparing Tables 1 and 2, the increase in requirements for brakes is evident.

A further condition is added by the increased use of the brakes in service. During normal service operation the piston transport brakes absorbed approximately 30% to 40% of the design normal kinetic energy, whereas the jet aircraft brake absorbs 40% to 60% of the design normal energy.

The airframe company engineers added to our problems by specifying torque limits for the brake. By limiting the static-to-dynamic brake torque to a ratio of approximately 2 to 1, low peak torque conditions would result to make lighter landing gear designs possible. This made the selection of the lining material more difficult. Summing up all of the conditions and adding the requirement of a conventional brake design (Figure 7), we are presented with a very difficult engineering job.

Brake manufacturers have two basic approaches to the design of the conventional transport brake. One approach is to use a full circle of the sintered metal linings on a steel core in combination with a solid disk. A second approach is to use a full-circle lining carrier with segments or spots of the cupped sintered lining material riveted to it. This in turn is used with a segmented disk. Of course, a mixture of these features could also be used.

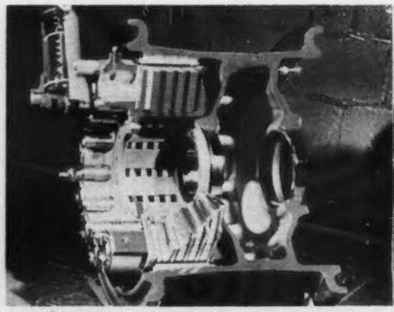


Figure 7
Cutaway of wheel and disk brake with deboost adjuster for Boeing 707

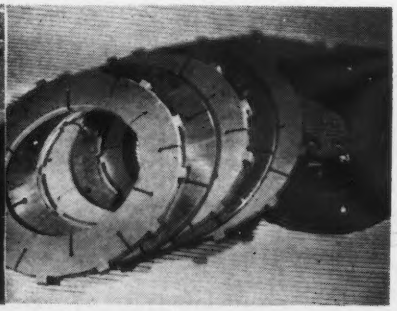


Figure 8
(l to r) Disks (external drive lugs), lining carrier assembly and torque plate with lining wear plates attached

Table 2

Aircraft	Type	Wheel Size	Bead Seat Dia-In	KE/Wheel Ft Lb	Brake Weight-Lb	Heat Sink Weight-Lb	KE/Lb of Heat Sink	Lining Material
Northrop T-38	Trainer	20 x 4.4	12	4.8×10^6	38.0	28.0	171,500	Metallic
Douglas DC7C	Transport	17.00-20	20	23.7×10^6	153.0	110.0	215,500	Metallic
Lockheed L-188	Transport	13.50-16	16	16.9×10^6	120.0	98.5	171,500	Metallic
Boeing 707-300	Transport	17.00-20	20	44.5×10^6	210.0	148.0	301,000	Metallic
AVRO CF-105	Fighter	29 x 7.7	15	22.3×10^6	*	65.0	343,000	Metallic
Douglas A3D-2	Bomber	44 x 13	20	38.0×10^6	*	128.0	297,000	Metallic
NAA A3J	Fighter	36 x 11	16	16.4×10^6	*	55.4	296,000	Metallic

* Wheel and brake weights cannot be separated as wheel bearing carrier and brake piston housing are one part.

Taking the first approach to the heat-sink design, that of the full-circle sintered lining and solid steel disk (Figure 8), we have a design with a minimum number of pieces. The full-circle carrier, by virtue of sintering the lining directly to the core, provides additional mass to the heat sink. It also provides the maximum lining area for improved wear and maximum torque development. We favour this type of design as we feel it results in the lowest manufacturing, overhaul, and maintenance costs.

The heart of the brake is the heat sink, which is made up of the disks and lining assemblies. Therefore, by necessity, the brake design starts with the components. We have pointed out before that considerable development work has been done to obtain disk material which will withstand high thermal shock, retain its toughness under high temperatures, and have wear resistance over a wide temperature range. One of the best disk materials known to date is the Timken alloy 1722AS. This material, when properly heat-treated, has a maximum operating temperature of over 2000°F.

When using 1722AS material in a multi-disk brake design, the disk size and shape, combined with the wide operating temperature range, may cause it to distort and shrink. Control of distortion and shrinkage in the solid disk can be brought within acceptable limits by careful design of the slotting pattern (Figure 8).

Requirements for the jet aircraft brakes dictate the use of metallic linings because of the very high heat-sink loadings (KE/lb of HS) and temperatures. Two basic lining compounds are in use in present day jet aircraft brakes. One is a sintered iron base; the other, a sintered bronze base. Both of these basic materials are mixed with various modifiers, such as ceramic particles, alumina, graphite etc, to obtain the specific characteristics needed for a particular brake design. As a general characteristic, the present sintered iron linings operate to maximum temperatures of approximately 1750°F, whereas the sintered bronze is limited to approximately 1500°F. Both of these materials, at normal aircraft brake energies, give approximately the same coefficient and wear characteristics. At the higher conditions, such as the rejected takeoff (RTO), the sintered bronze materials wear considerably more rapidly than the sintered iron base materials. However, the sintered bronze material produces a very even coefficient of friction and falls closely within the required 2 to 1 ratio of static-to-dynamic torque limits. When used in the brake design properly, it produces no chatter, thus giving a very smooth brake. On the other hand, the iron base materials up until recently produced higher static torques; however, they produced greater torque variation and chatter during low speed braking applications. Iron base material, being somewhat harder than the bronze base lining, causes some disk wear. Combining the best of the presently developed lining and disk materials, we have been able to meet the latest torque and kinetic energy requirements.

Along with the heat sink there are two other major brake components — the piston housing and torque plate.

The piston housing assembly (Figure 9) houses the actuation system, pressure plate retraction, and the brake adjustment features. The housing itself may be cast or forged out of magnesium or aluminum. Although each material and method of manufacture has certain advantages, it appears that generally forged aluminum will rate first, as it has very good strength, fatigue properties, and corrosion resistance. The other components of the piston housing assembly, although important, will not be covered.

The torque plate (Figure 8) attaches to the piston housing and holds, as well as backs up, the heat sink parts. The stationary parts of the heat sink are keyed to the torque plate. It is usually made of 1722AS steel as it must transfer the torque developed by the friction components of the brake to the axle flange. At

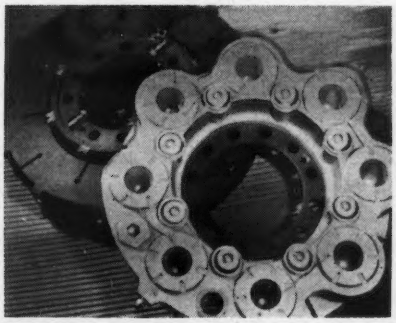


Figure 9
Piston housing assembly in foreground; torque plate with heat sink assembled in background

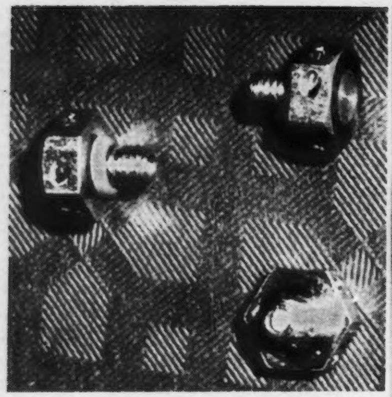


Figure 10
Thermal bolts with silicone O ring in place

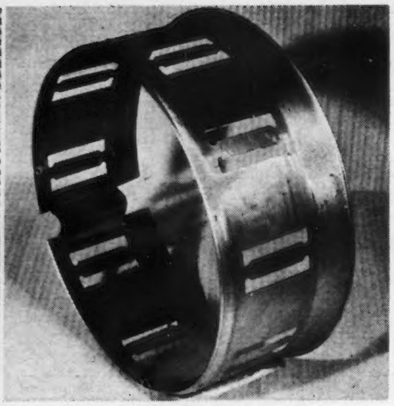


Figure 11
Stainless steel heat shield used in a military main wheel; cutouts are for brake drive keyways

the same time it must resist an axial force due to the brake actuation pistons. As a method of weight saving, our latest designs utilize the brake flange mounting bolts, not only to fasten the brake to the axle flange, but also to hold the piston housing and torque plate together.

Now that we have raised the maximum operating temperatures of the heat sink, the effect on surrounding parts must be considered. Service operations can and do cause more heat problems today than in the past.

There are three conditions in normal operation of an aircraft which will produce an extremely hot brake that can lead to problems in the brake and wheel-tire combination. One of these is a rejected takeoff which requires high energy absorption and the resultant high brake temperatures. A second condition is where a moderate stop has been made with the aircraft and it is then taxied over a long distance and, from either intentional or unintentional use, the brakes have been dragged for quite a period of time. The total energy absorbed can, in many cases, equal or exceed the rejected takeoff energy. The third condition would come from operations, such as pilot training, where a series of landings and full stops are made in quick succession so that each succeeding stop has added energy to the brake until the total energy absorbed is equal to or greater than the rejected takeoff condition. The high temperatures produced in the brake by these conditions will, if not prevented, be dissipated in conventional fashion to the wheel, tire, axle, and piston housing.

Without proper protection this causes leakage of the seals in the brake, destruction of the heat treat in the high tensile axles, and weakening of the wheel-tire structure. It also increases the contained air temperature to the point where explosive failure of the tire and wheel may result. Protection is needed for the components that surround the high temperature heat sink of the brake. In some cases, to protect the axles, a stainless steel shield slightly larger in diameter than the axle is placed between it and the brake. This effectively keeps the axle temperatures within reasonable limits.

To protect the piston housing of the brake assembly, insulation is attached to the ends of the pistons, or annular ring. In addition, an insulating board similar in shape to a disk is placed between the actuation unit and the pressure plate of the brake. These two methods, plus the maximum air gap possible, have proved satisfactory in insulating the piston housing from these extremely high heat-sink temperatures.

The wheel and tire combination presents a slightly different problem. When the wheel and tire become dangerous from extreme abuse of the brake equipment or a maximum RTO, thermal plug bolts (Figure 10) are used in the wheel to prevent an explosive failure. This small bolt is filled with low melting alloy. At least three bolts are usually placed above the brake assembly in the tubewell area of the wheel. Depending on location, the thermal melting material in this bolt is alloyed for temperatures of 250° to 400°F. Melting out of this alloy releases the tire pressure and prevents explosion of the overheated wheel and tire.

For brake designs where normal energies or taxi conditions will produce problems with the wheel and tire, a heat shield (Figure 11) is used in addition to thermal bolts. This shield is usually stainless steel or stainless steel sandwich, with an asbestos filler placed between the brake and the tubewell of the wheel. It does a very effective job of reducing wheel temperatures due to normal in-service conditions.

MILITARY AIRCRAFT BRAKES

The brake designer has a much freer hand in designing brakes for military aircraft. He is not limited to conventional brake designs when more radical designs are necessary to meet the light weight and high energy requirements. Long service life, although desirable, is not a necessity if higher brake weights would be required to obtain it. Of course, each brake design will have to meet the specifications of the airframe company and the military organization buying the aircraft.

One of the first considerations for a brake design is the envelope into which the brake package must fit. Generally, the size for tire, wheel and brake is established in this order and, when you consider that the trend is to the smallest possible tire to handle the load requirement, the result is in many cases a very small brake envelope. In some cases a conventional commercial-type design can be utilized with good success. However, in other cases, the more expensive design must be used to produce a brake that will meet all the necessary performance specifications. For current military designs which utilize the conventional approach it is, of course, necessary to use the latest of the sintered lining materials and the best of the disk steels. The only variation from the commercial approach in

design would be the use of slightly higher loadings on the heat-sink parts, with the resultant higher temperatures and shortened service life. These conditions may be acceptable because of the type of use a high performance military aircraft sees. A brake design typical of this approach is the one used on a Northrop T-38 jet trainer (Figure 12).

New versions of current high performance military aircraft, as well as new aircraft designs, are requiring considerably more brake capacity within the already existing or smaller envelopes. Examples of this situation are the increased gross weight versions of the Douglas A3D-2 and the recently designed North American A3J.

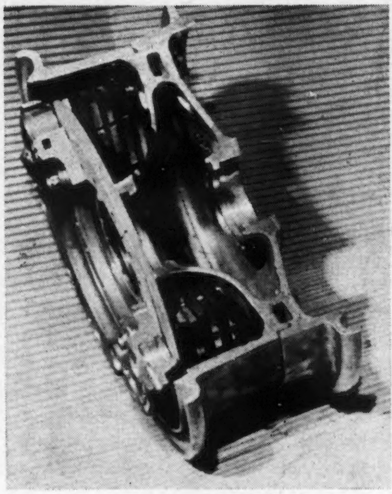


Figure 12
Cutaway of main wheel and disk brake used on Northrop T-38

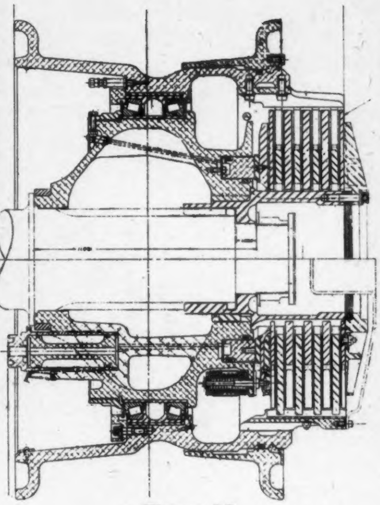


Figure 13
Sectioned drawing of main wheel and disk brake for Douglas A3D-2P

The A3D-2 brake requirements presented an interesting problem. The axle size as well as the wheel well space was already established. However, the increased gross weight conditions of the aircraft, plus other taxi considerations, increased the maximum KE to the brake from 21,370,000 ft lb to 38,000,000 ft lb. The expanding of the conventional designed brake, used on the lighter aircraft to handle the much higher kinetic energies, was impractical for reasons of space and wheel temperature problems. Therefore, a radical new design approach (Figure 13) was used for the newer higher gross aircraft.

The first design consideration was to get the heat-sink mass outside the wheel contour to eliminate high temperature wheel problems. This, of course, required that the actuation system then be inside the wheel contour. To solve this problem, a bearing carrier was designed which supported two 15 inch wheel bearings as well as housing the actuation and retraction system of the brake. The stationary heat-sink components were keyed to a steel torque tube which was press fitted into the bearing carrier and splined to the end of the axle. A backup plate was bolted to the end of the torque tube by twelve bolts. This part resisted the forces applied to the heat sink by the actuation piston. The wheel used on this installation was of a barrel section. It rotated on the two large diameter bearings and drove the rotating members of the heat sink through a torque ring bolted to the outer flange of the wheel assembly.

This design approach permitted the use of much wider disk and carrier faces giving more area per face, thus permitting fewer parts to produce the necessary torque. As the brake heat sink is mounted outside the wheel contour, it can be operated at much higher temperatures while having little or no effect upon the wheel or tire. The brake heat sink is also exposed in this position for the best possible cooling from air movement.

To make the most of these unusual designs for military aircraft, the best high temperature disk and lining materials available must be used. These materials are, basically, the same as those used in the commercial brakes. However, the selection of a sintered metal lining compound will be a compromise to obtain the desired temperature limit, coefficient, and smoothness characteristics. Care will also be required in the disk design and slotting to obtain stability and reliable service life.

Some side advantages to this radical design approach are the possibility of shorter axles and easier heat sink replacement. By removing the twelve pressure plate retaining bolts, the heat sink may be changed without jacking the aircraft or breaking the hydraulic lines. This type of change can be made in ten to fifteen minutes without the requirement of special tools.

The North American A3J wheel and brake equipment (Figure 14) required the same radical design approach as the A3D-2 to meet the necessary weight and envelope requirements. However, it had one requirement more stringent than the A3D-2 in that the brake had to be housed completely within the wheel contour. Because of this, high wheel temperatures were experienced and a stainless steel heat shield was designed and used between the brake and the tubewell

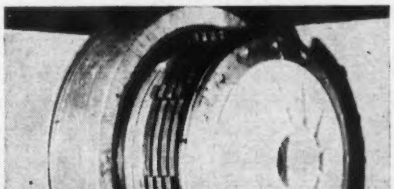


Figure 14
Cutaway showing disk brake location within wheel; wheel and brake assembly for North American A3J

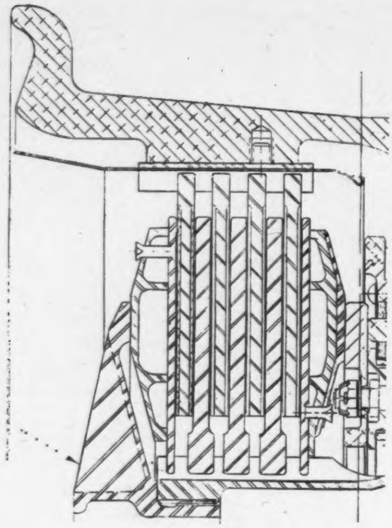


Figure 15
Sectioned drawing of North American A3J disk brake heat sink

of the wheel to prevent temperature damage to the wheel and tire. The feature of changing the heat sink without jacking the aircraft was retained. However, an improvement was made by replacing the twelve bolts used on the A3D-2 design with one new retainer plate, threaded so that it also served as the nut for locking the brake heat sink together.

There were also some new features in the heat-sink components which improved the over-all brake performance. In most conventional designs the pressure plate and wear plate, which are at opposite ends of the heat sink, reflect the deflections of the piston housing and torque plate. This is owing to their proximity to these major components. In the case of the wear plate, it is usually attached directly to the torque plate. When high application forces and high temperatures cause deflections of these major components, uneven loads result across the faces of the stationary and rotating members of the heat sink. This produces uneven wear and results in lower brake torque capability.

In the A3J design, to eliminate the effects of deflection on the rotors and stators and to insure that they are squeezed evenly over the entire braking surface, two rigid cast plates are used at each end of the heat sink (Figure 15). The plate at the pressure side of the heat sink assures that the piston force is distributed evenly over the braking surface. At the other end of the heat stack, the axial loads are transmitted through the back plate at its center point to the retainer nut. The attachment of the back plate to the retainer nut allows it to float straight when the brake pressure is applied. Therefore, any deflection is limited to the retainer nut and does not affect the heat-sink components. By this approach to the heat-sink design, we obtain the maximum torque and wear from the brake.

A brake, very similar to the A3J unit, was designed for the Mark II version of the Avro CF-105. By using this new approach, the wheel and brake fit into the existing space available in the aircraft wing. The maxmium brake energy requirement for the Mark II version was nearly double the maximum kinetic energy required for the earlier aircraft. However, the new wheel and brake design was only 3 lb heavier than the original equipment. This is just one of several examples of the effectiveness of this type of design where maximum brake performance is required. It should be remembered that designs of this nature usually require special materials and intricate manufacturing methods, which tend to make the equipment more expensive.

FUTURE BRAKE EQUIPMENT

The latest aircraft designs are continuing the trend to require higher torques, higher capacities, lighter weights, and smaller sizes for future brake equipment. With these requirements facing the brake manufacturers, we are constantly investigating methods for improving current designs by unusual approaches, exotic materials, or entirely new concepts of brake design.

The present heat-sink materials are now being operated at about their maximum limits; therefore, it would be logical to investigate other materials that might be possible replacements for them. Several exotic materials are being investigated for use as brake components. To date none of the materials investigated hold much promise for general brake use. Because of this we must work on design approaches for improving the current heat-sink brakes, or developing new braking concepts.

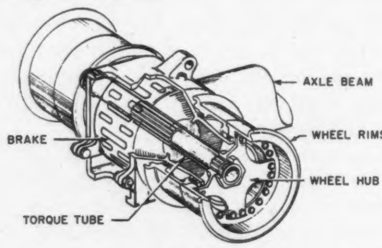


Figure 16
Cutaway of wheel, axle and brake assembly

Advance design

A unique design approach is being used for the wheel and brake equipment for a future high-performance aircraft (Figure 16). In this approach the landing gear, brakes and wheels are designed as an integrated unit. The end of the bogie beam is designed to house a brake capsule, as well as being support for the main wheels. The brake capsule is mounted between the wheels which removes it from the critical wheel and tire area, so that the generated brake heat will have little effect on these components. Figure 16 shows a cutaway of the design and you can see the brake capsule is bolted at three locations to the bogie beam. Through these connections the torque from the stationary brake parts is transmitted to the gear of the aircraft. A torque tube is splined to both wheels and to the rotating members in the brake capsule, and transmits the torque from them to the wheels, tires and ground. An interesting feature is that it requires removal of only three bolts and the torque tube to remove the brake assembly from the landing gear system. This can all be done without requiring the

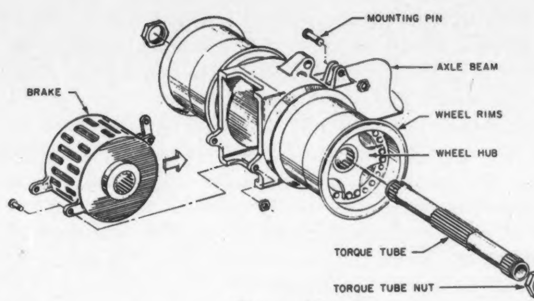


Figure 17
Wheel, brake and axle assembly showing removal of brake heat-sink cartridge

aircraft to be jacked. This design also permits the wheels to be removed from the aircraft without affecting the brake unit in any way.

In a design of this type of brake, something other than the normal rubber seals is necessary. To make this brake function properly, special very high temperature all-metal seals are used and tests indicate that they are most successful.

Another side feature to this type of design is that several brake cartridges could be designed to be utilized under special service conditions (Figure 17). In this way each type of military mission or commercial operator could select the brake cartridge that most nearly fitted his needs. In five to ten years this brake design may be quite common on many of the high performance aircraft.

Auxiliary brake cooling

Other avenues are being investigated to increase the capacity and life of the conventional brake designs. They are essentially auxiliary units for cooling the brake assembly during or after the brake heat has been developed.

One of the first auxiliary systems tried was the use of a water spray. This spray was applied directly to the heat-sink members during the brake stop. It provides approximately 10% increase in the capacity of the brake; however, there is a problem of increased cost and weight due to the piping system which has prevented its use. However, further development along this line may produce a serviceable design.

Another recent approach to auxiliary cooling methods for conventional brakes is being studied. This is the use of a high volume of air directed over the brake assembly during a stop, and the taxi and parking that follows. This volume of cooling air may be provided by the use of a motor-driven fan mounted on the axle in the area of the wheel and brake. Another method would be to duct bleed air from the jet engine so that it passes over the brake assembly. These methods of brake cooling do not help much during a 15 to 40 second brake stop. However, they may be effective in reducing peak heat-sink temperatures and shortening the brake cooling. This may benefit the newer commercial jet aircraft by reducing ground time for cooling heat-sink brakes. The amount of benefit from this type of cooling must be evaluated in terms of the cost and complexity of the additional equipment needed.

New braking concept

An entirely different approach to the problem of increasing brake capacities, extending their service life and, generally, removing the brake heat problem from the wheel area has been accomplished by the B. F. Goodrich liquid-cooled brake system. There is a fundamental difference between this system and conventional brakes. It takes the idea of auxiliary cooling of a disk brake one step further — that of removing the heat from the brake area and dissipating it almost immediately at a distant point. The components of this system are interdependent and, therefore, can be thought of only as a system and not as just a liquid-cooled disk brake.

The liquid-cooled brake system is made up of a conventional-appearing disk brake, a liquid-to-liquid heat exchanger, expansion chamber, circulation pumps, and transfer valve (Figure 18). The concept of this system is to remove the heat generated at the friction surfaces by a fluid and dissipate it at some point external to the brake itself. The primary system, which is an enclosed pressurized fluid, is pumped between the brake housing and the heat exchanger. This low-freezing point fluid carries the heat generated by the brake to the exchanger, where the heat is transferred to a secondary fluid, which is then heated up and boiled off during high-energy stops.

The function of the brake in this system is to generate heat by friction and develop the torque necessary to stop the aircraft (Figure 19). The brake can be either a single- or double-rotor unit; however, a single rotor will be used as an example for ease of explanation. Both the large annular piston and the back plate of the housing are faced with copper. Behind these copper faces circulates the primary fluid. The rotor is

Figure 18
Cutaway drawing of a liquid-cooled brake system installed on a four-wheel truck landing gear

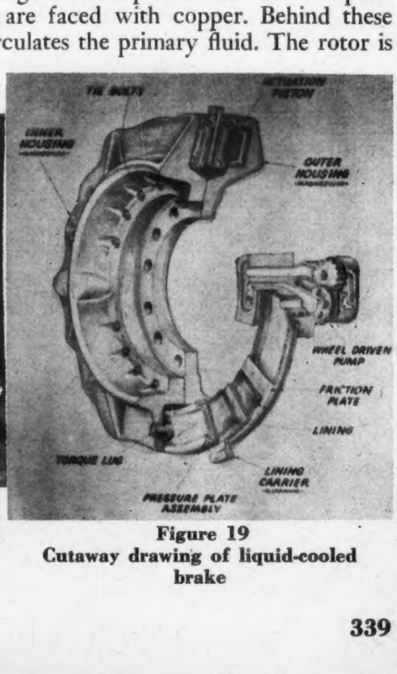


Figure 19
Cutaway drawing of liquid-cooled brake

a light metal and has a soft organic lining bonded to it. It is possible to use this lining material as the interface temperatures of the brake operate normally at 300°F and, even in the worst conditions, rarely exceed 400° to 500°F. Also, the soft organic material is needed as the copper faces of the circulating chambers would not resist the wear of an abrasive lining material. The primary circulating fluid is a glycol-water mixture to withstand low temperatures without freezing, as well as provide a fluid of high specific heat. The large annular piston is actuated by a separate fluid system, which is also glycol-water, to avoid problems of fluids intermixing resulting from a seal link.

The hot fluid in the primary system is pumped from the brake into the liquid-to-liquid heat exchanger where it is cooled and then returned to and through the brake. The secondary fluid of the heat exchanger, when being raised in temperature and boiled off, dissipates the heat generated by the brake. The number of repetitive brake stops or the highest KE input from an RTO governs the amount of the secondary fluid carried. Of course, the quantity of secondary fluid is usually based on the condition in which the maximum KE is generated in any one stop, as the ease of refilling this secondary fluid makes it impractical to carry additional fluid. The secondary fluid is pure water and we do not add a glycol or other such materials to prevent it from freezing. On many tests run to date freezing of the secondary fluid does not in any way affect the structure of the heat exchanger, and merely adds to the thermal capacity of the brake system.

High flow rates are necessary to make this brake perform well under extremely high energy conditions. To obtain the flow of the primary fluid, wheel-driven pumps are mounted on the brake assembly. The pumps are driven by a ring gear attached to the wheel. This is an ideal setup, as the KE input to the brake is a function of the square of the speed of the aircraft. Therefore, at the higher speeds, when the highest KE input to the brakes is experienced, the pumps are working at their top flow. Present designs of the liquid-cooled brake system require a peak pump output of 200 gpm.

Of course, to handle the expansion of the primary fluid under increased temperature an expansion tank is put in this closed system. This tank is pressurized to approximately 25 psi so that cavitation in the pumps is prevented.

The brake is actuated by a large annular ring and low actuation pressures are required. As most aircraft systems are approximately 3000 psi, a deboost valve in the hydraulic system is necessary. We use a transfer valve which not only deboosts the system pressure by a factor of approximately 10 to 1, but at the same time is used to separate the aircraft hydraulic fluid system from the brake glycol-water actuation system. By doing this, we eliminate any of the inflammable fluids in the wheel and brake area. This same unit acts as a lockout for line or seal failures downstream.

The liquid-cooled brake system is more complex than the conventional disk brake equipment. Being comparable weight-wise with conventional brakes, we feel that its exceedingly long service life, indicated by current in-service tests, will more than compensate for its higher initial cost. Along with this, it removes some of the current problems that exist with conventional heat-sink brakes. The most important of these is removing extremely high temperatures from the wheel cavity which can cause, at times, complete destruction of the heat-sink brake and explosive failures of tire and wheel assembly. It also removes the danger of brake fires due to hydraulic fluid leaks.

Current service tests of this equipment include approximately 3 years on a twin-engine test airplane, used by the USAF, in which the brake was run 18 months without maintenance. After overhaul and correction for some corrosion in the system, it was reinstalled and has been running since that time. As a comparison, the conventional brakes designed for that aircraft last approximately 1 month between complete overhauls.

The second installation has been on the prototype of a jet transport for over 2 years. Its use on this aircraft eliminated the long delays between runs for engine and other ground-handling tests where, when heavy braking is required on the disk-type heat-sink brake, ½ hr to 1 hr cooling is required before another run can be made. With the use of the liquid-cooled brake system, there may be only a 10 min delay between each test run and this is used primarily as a precautionary step for checking the secondary fluid in the brake and refilling when necessary.

CONCLUSION

We have very briefly covered the design of past, present and future aircraft brake equipment. To keep pace with the rapidly advancing aircraft industry, the wheel and brake manufacturers have had to explore and develop materials to their fullest to meet the ever increasing requirements for higher kinetic energies and torques, while producing brake equipment in the lightest and most compact form. New design approaches are necessary to further improve brake designs as we have reached the limits of some of the available materials.

The future designs and developments should improve the brake equipment to meet the more stringent demands for the newer higher performance aircraft.

BOOKS

Elements of Flight Propulsion. By J. A. Foa. John Wiley & Sons, Inc., New York, 1960. 445 pages. Illus. $12.50.

This text starts with a review of the basic concepts of thermodynamics and compressible flow and, after an excellent chapter on "Changes of the Frame of Reference", the author introduces the subject of non-steady flow. About half the remainder of the book enlarges upon this subject. A number of practical examples, such as the wave engines, pulsejets and pressure exchangers, are explained and used to fix the non-steady flow concepts in the reader's mind. In this respect the book is one of the best on the subject of non-steady flow which this reviewer has seen. It will be a useful addition to the library of anyone with an interest in this subject, even though he may not share the author's optimism with regard to the practical application of non-steady flow to powerplants in view of the problems of off-design operation and mechanical design.

The coverage of the more conventional material on thermodynamics and steady flow is clear and concise. The price asked for this publication is considerably high for the technical value of the data contained therein.

G. C. Best

Fatigue Testing and Analysis of Results. By W. Weibull. Pergamon Press, New York, 1961. 305 pages. Illus. $15.00.

A glance at this book's bibliography will convince the reader – should he need convincing – that Mr. Weibull is an authority on the subject of fatigue. Therefore no additional comment appears warranted about this well known gentleman.

When designing a fatigue test program, one of the problems is that of collecting as much data on the specific subject as possible, so that the chances are small of duplicating similar work. Several professional bodies publish bibliographies on fatigue which help in this respect. Mr. Weibull's book will now also contribute to the supply of references needed on almost every aspect of fatigue. Although the book is primarily a reference book, chapters 8 and 9, "Presentation of Results" and "Analysis of Results" respectively, are very useful for direct application. However, while the book is an excellent publication, it is likely to be more useful to the research worker than the average aircraft engineer. For example, the reader will want an above average knowledge of statistics to appreciate chapter 9.

Chapter 1 presents the symbols and nomenclature used throughout the book. In general, the proposals of ASTM Committee E9 on Fatigue have been used. Chapter 2, "Fatigue Testing Methods", presents nearly every type of test method currently in use. Short-life tests, long-life tests, cumulative damage tests and service-simulating tests, are among the methods discussed. Chapter 3, "Fatigue Testing Machines and Equipment", is a most exhaustive collection of data. In addition to the usual testing machines for repeated bending, combined bending and tension etc, it is interesting to note a section on calibration and checking of testing machines, this aspect of fatigue work being of the utmost importance. Chapter 4, "Instruments & Measuring Devices", presents all the instruments specifically required for conducting fatigue experiments. Such methods as ultrasonics, X-Ray and electrical-resistance are discussed. Chapter 5, "Test Pieces: Design, Preparation, Measurement & Protection", is extremely useful in so much that some detailed information is given for the design of test pieces. All types of test pieces are considered from the simple notched bar to a complete structure. Chapter 6, "Factors Affecting Test Results", should be very useful when setting up a test program, as it will help in deciding on the important variables. Chapter 7, "Planning of Test Programs", is too general and far too short. The planning of a fatigue experiment is a very difficult, yet necessary, part of a program if one is to get the most from the available funds and, therefore, several examples showing the statistical implication would have been most useful. The use of the Latin square for these examples would have shown the practising engineer just what procedures were required. (Figures 73.1 and 74.1 mentioned in the text do not appear to be in the book.) Chapter 8, "Presentation of Results", is an excellent chapter, containing not only references but also actual details and examples. After reading this chapter, one should have a clear idea how to present test results, especially in a statistical manner. Chapter 9, "Analysis of Results", is again an excellent chapter providing the reader has an above average knowledge of statistics. The research worker will find this chapter extremely useful, but the aircraft test engineer will find it very difficult reading.

Concluding, it can be stated that Mr. Weibull's book is a most excellent reference source which will probably be of more use to the research worker than the average aircraft engineer.

E. Aubrey

Rocket Development: Diary of the Space Age Pioneer. By R. H. Goddard. Prentice-Hall, New Jersey, 1960. 222 pages. Illus. $2.45.

Robert A. Goddard is held to be the American father of rocketry and he certainly deserves full credit for his lifelong devotion to his work. The major tragedy however was that his many successful endeavours were not recognized by his country – the vision of the many pioneers was, in consequence, first achieved by another power which was willing to support its enthusiastic engineers and scientists.

In retrospect it is most surprising that any nation could make the same mistake twice and yet with the defeat of the Nazi forces in 1945 complacency was the order of the day, and both Goddard and the German scientists were forgotten until once more it was almost too late. The lesson to be learnt is obvious and it is therefore disappointing to find that, in glamorising Goddard, this book made no attempt to probe into the failure of a free enterprise society to take a deep interest in technological and scientific advances.

The chronological record of Goddard's laboratory work is interesting as it shows him to be a prolific inventor possessing uncanny engineering insight. His problems are faced up to in terms of hardware and as he struggles with the liquid oxygen and gasoline which he uses in his rockets a weak link in his work becomes apparent. This is the lack of facilities for fundamental scientific studies on propellants and combustion phenomena. Many of his troubles would have disappeared if he had used self igniting propellants; his determination to make the rather fickle LOX/gasoline combination function may have delayed recognition of his work. His choice

even continued to influence subsequent American workers and it is only relatively recently that one reads that the use of more attractive propellant systems is being actively pursued.

This book is primarily for the student and collector since it cannot be said to be more than an introduction followed by Goddard's condensed personal notes. The price is certainly not excessive and people working in the field of applied science should certainly read it. It demonstrates that recognition of one's endeavours is often slow and also that more than the hardware aspect should be considered when development problems arise.

L. A. Dickinson

Aeronautics and Astronautics — An American Chronology of Science and Technology in the Exploration of Space 1915-1960. By E. M. Emme. Foreword by H. L. Dryden. National Aeronautics and Space Administration, 1961. 240 pages. $1.75.

In his preface the author says "Some readers may criticize the selection of events. They may also be unappreciative of the fact that calendar-located events are not all of equal historical significance and do not necessarily appear in sequential order". They may indeed.

This book is a curious hotch-potch of information. Much of it is significant and much of it is, in my opinion, of no significance at all to "the Science and Technology in the Exploration of Space". In the latter category I would include "January 19 (1940): Maj. James H. Doolittle elected president of the I.A.S." (such Presidential elections are not recorded as a matter of course) and "During December (1954); "Man in Space" produced by Walt Disney". As one glances through the main portion of the book one is constantly struck by such trivialities and is only restrained from exploding by the author's admission that some readers may criticize the selection of events.

The book also has a misleading habit of giving names to aircraft types before such names were introduced. For example the item in 1938 "October 19: Curtiss XP-40 Tomahawk made first flight" — the name Tomahawk was not given to the P-40 until 1940. This occurs in several instances; some device such as "(later called Tomahawk)" would have been better.

Though this claims to be an American Chronology, it includes many items of significance referring to non-American events and developments — on the whole, with admirable accuracy so far as I know. But again the selection is odd. The development of the Mosquito receives three mentions; the Spitfire one; the Hurricane two; the Wellington one; and the Lancaster none at all. Five references are made to Canada, principally in its capacity as a site for U.S. balloon and rocket launchings. In British-U.S.A. dealings in the early part of the war effort, where one might legitimately expect accurate detail, one finds, in 1938, the British Purchasing Commission (not in existence at that time) ordering 200 Hudsons in December; the first Hudson order was certainly placed in June or early July of that year. Moreover I feel that it is scarcely fair to the Harvard to claim the Hudson as "the first American-built aircraft to see operational service with the R.A.F. in World War II"; the Harvards were in service (perhaps not combat but certainly operational) before the Hudsons — and were, incidentally, a far more significant aeroplane.

The work includes Appendices, tabulating Satellites and Space Probes, World Records, Balloon Flights, Honors and Awards, and Membership of NACA. These are useful but the Appendix on World Records deliberately makes some astonishing omissions. By excluding "seaplane records or discontinued categories" it excludes the Supermarine S5 and S6 and the Gloster VI from the table of "Maximum Speed over Straightaway Course" — just because they had floats instead of wheels, I suppose.

I noticed a few typographical errors; for example, Moreton Valenee on page 46 should surely be Moreton Valence.

The way of the historian is hard, for he is always open to criticism in his selection of events. But he must be 100% accurate in what he does record and, for this reason, though this work contains a wealth of information, I distrust it and must therefore condemn it as a basic reference. It would have been much better if it had been less ambitious and had confined itself to the American scene.

H. C. Luttman

Progress in Combustion Science and Technology. Edited by J. Ducarme, M. Gerstein and A. H. Lefebvre. Pergamon Press, New York, 1960. 226 pages. Illus. $10.00.

This is the first volume of a series to be published annually covering propulsion and combustion related to aeronautics. Each book will contain review articles on fields in which recent advances have been made. Specialists will survey their fields and critically review the recent advances. No attempt is being made to standardize nomenclatures, viewpoint or tie the articles together in any way, so they must be reviewed separately.

Flow Visualization Techniques, by E. F. Winter, English Shell, makes a case for water testing to simulate the unlit combustor after similarity criteria are given. Then measurements and visualization in operating combustion chambers are reviewed briefly. The main report is concerned with air and water testing to obtain the large scale combustor flow patterns and is well illustrated. This first paper is a model for the intentions of the book — an excellent general survey with very detailed references, followed by a good and complete summary of some of the latest work.

Chemical Analysis in Combustion Chamber Development, by B. Toone, Rolls-Royce, starts with a brief but useful review of the main chemical reactions and the available techniques for analysing over-all gas composition. Some Rolls-Royce work on detailed gas composition in one of their combustors is given. This last part is a streamlined presentation of the author's 1958 paper in the Seventh Combustion Symposium. A modest list of references concludes this excellent survey paper.

Aerodynamic Influence on Flame Stability, by M. V. Herbert, NGTE, is a large and detailed continuation of the author's 1957 AGARD paper. Stability and efficiency for simple recirculating cans with premixed fuel and air are collated. The parameter shows that chemical reaction (oxidation) time is a limiting factor at the low test pressures involved. A survey of stability work on flame behind a variety of baffles shows, for lean fuel-air mixtures, a criterion $\frac{(\text{Velocity})}{(\text{dia}\ \sqrt{C_D})}$ which is a simple function of drag coefficient. The inclusion of unpublished material and an extensive bibliography will make this paper of extra interest to other researchers. Unfortunately, the more general reader will find that he is assumed to be completely familiar with the author's earlier paper.

Geometric-Optical Techniques in Combustion Research, by F. J. Weinberg, Imperial College, London, is a summary of a forthcoming book. The author examines combustion measurements dependent on light-deflection (hence geometric-optical) and involving schlieren or shadowgraph techniques. The paper is very well illustrated by 29 figures and photographs. It is of primary importance and interest to those working on fundamental combustion studies of flame fronts, droplet burning etc. For lack of space the author has had to assume "the entire background of the optics and combustion theory involved". As a result anybody not actively engaged in using optical techniques for fundamental combustion research may well find this paper indigestible. A very large list of references is included.

Flame Quenching, by A. E. Potter, NASA Lewis, is a brief historical survey, followed by a critical review of four standard test methods. The simplest and apparently best method is to check for flash-back after cutting off the fuel flow to an established flame. The assumptions used and final equations obtained by existing theories of quenching distance are covered quickly. A critical comparison of these theories with experimental results does not show any one best theory; ambiguous test results are blamed for this. Experimental results are given showing the effects on quenching distance of fuel concentration, operating pressure, inlet temperature, wall shapes etc. Pressure gradient causing flow through the quenching holes has a profound but still undetermined effect. This data is of practical importance for designing flame arresters and for checking interconnectors on multi-can engines. A large bibliography completes a paper that is a model as a clear survey of a rather limited field.

Ignition in Liquid Propellant Rocket Engines, by E. A. Fletcher and G. Morrell, U. of Minnesota. Ignition delay is of prime importance to rocket engines. A simplified theory is developed to show that delays greater than 1 or 2 milliseconds will cause the combustion chamber to exceed its operating pressure, unless the fuel is throttled prior to ignition. Test results on self-igniting fuels (hypergolic) are critically reviewed, the published data being largely for amine type fuels with nitric acid as the oxidant. Research fuels which are not self-igniting, typically hydrocarbons and oxygen, are surveyed according to the ignition method used: hot surface, flames, hot gases and spark. Finally application of the test data to rocket design is discussed. The test data are discussed critically but not presented, only referenced. Thus the review is a guided tour of the extensive list of references. It does not summarize the data nor present it even in part. A well written survey, but it cannot be used by designers without obtaining the references.

The idea of collecting up-to-the-minute survey reviews by leading authorities in an annual book is excellent. In this first volume some of the reviews are marred by omission of test data or background information necessary for complete understanding. However the combustion designer will find one or more articles of interest and profit, while the research engineer will value them all. The book is heartly welcomed and recommended.

H. C. Eatock

Dynamics of Real Fluids. By E. G. Richardson. The Macmillan Co. of Canada Ltd., Toronto, 1961. 231 pages. Illus. $8.50.

This is the second edition of a slim volume by an eminent experimental researcher in the physical aspects of fluid dynamics and related acoustics. The revision was completed shortly before his recent death. The most striking feature is the breadth and variety of the topics covered; the short table of contents hardly gives the picture: (1) Introduction: The Fluid State; (2) The Classical Approach; (3) Fluids of Small Viscosity; (4) The Flow of Compressible Fluids; (5) Hypersonic Flow; (6) Aerodynamic Noise; (7) Fluids with a Temperature Gradient; (8) Liquid having a Free Surface; (9) Behaviour of Particles in Suspension in a Stream; (10) Fluids showing Anomalous Viscosity: Suspensions; (11) Elastic Liquids; (12) Magnetohydrodynamics.

The following specific subjects – the full list is many times as long – caught the reviewer's eye for one reason or another: kinetic theory, experimental Stokes flow, Kármán vortex street (and sound generation), periodic boundary layers, acoustic streaming, statistical aspects of turbulence, two-point correlations and their measurement, meteorological considerations, jet noise, edge tones, boundary layer noise, instability of fluid heated from below, hot-wire anemometer and various applications, waves on a free surface, wave-making by wind, impact on liquids and sounds produced thereby, cavitation, break-up and drop formation in liquid jets, formation of sand dunes and ripples, erosion, streaming birefringence, flow of emulsions, dynamics of sols and gels, boundary layer of a plate in a magnetic field.

The compression into 222 pages plus index gives the book somewhat the character of a lengthy review; it is too condensed to be a text. As a review it reflects the manifold interests of Prof. Richardson, himself an important experimental contributor for more than three decades. The book is unusual in citing the original papers of the great contributors, e.g. Euler, Navier, Stokes, Oseen, Reynolds, Rayleigh, Helmholtz, Taylor, Prandtl, Kármán etc. With this emphasis on the classical contributions there is a corresponding failure – in many cases – to cover modern contributions and experimental techniques.

The point of view is that of the experimentalist throughout. The theoretical discussion is sometimes illuminating, sometimes puzzling, because it is so telescopic. The author often presents results without derivation. At other times he starts from first principles, supplementing the mathematics with physical arguments, but these are frequently oversimplified. Loose statements have been found by the reviewer in his own fields of specialization. On the whole, therefore, the explanatory exposition is concluded to be valuable as an introduction but not authoritative.

Some errors and misprints have been noted. For example, ζ_1 and ζ_2 have apparently been interchanged in the next to last line, p 129, and the equation contains several misprints. Also in the magnetohydrodynamic flow of Hartman, pp 21-221, the magnetic field should have been taken normal to the wide walls, that is, parallel to a rather than to b; the *emf* e_z and current I_z are parallel to the y axis, but refer to a fluid layer at depth z.

If the limitations are borne in mind, this small volume commends itself as a survey ranging beyond the usual scope of books on fluid dynamics. The coverage might be characterized as conventional fluid dynamics with a physics flavour, blended with meteorology, rheology, and acoustics.

Dr. H. S. Ribner

C.A.I. LOG

SECRETARY'S LETTER

THE INSTITUTE'S NAME

A SECOND ballot on the question of the Institute's name was held between the 5th and 20th October. The first ballot, held in July, indicated that there was substantial support for the Council's recommendation that the name should be changed, though the majority on that occasion just failed to reach the 2 to 1 ratio required by the By-laws; that ballot also indicated a marked preference for "Aeronautics and Space", rather than "Aerospace".

The Council, and the Planning Committee before them, had devoted much thought and debate to this question and felt strongly that a change was vitally necessary to the Institute's future. As I explained in my letter in the September issue, the existing name undoubtedly creates a false "public image" – the public being what it is – and this is rapidly becoming a serious handicap. The situation had to be corrected as quickly as possible.

Feeling that it had the support of the majority, the Council decided to go to the membership again, this time with the more specific proposal that the name should be changed to the "Canadian Aeronautics and Space Institute". This proposal has been carried – the scrutineers' report appears in the Announcements. It will now be necessary to translate this into the verbiage of the Bylaws and hold yet a third ballot on the formal Amendment. It then remains for the result to be submitted to the Secretary of State for approval. It will be many months yet before we can begin to use the new name officially, but we can begin to take some preliminary steps.

THE CREST

The change of name will not entail any substantial change in our crest. The Council has decided to retain the three geese and the maple leaf on a light blue field. However, the name circumscribing the emblem will have to be altered and, in making this change, the opportunity will be taken to reverse the present arrangement of colours; we shall have silver lettering on a dark blue field, in the full colour version, or white lettering on black, in the ordinary black and white reproduction.

The President's Badge has always been "wrong" in this respect and, during the last two years, so has the IAS rendering of our crest on the green-and-yellow Notices of the IAS/CAI Meeting, which they have so kindly printed for us. But, wrong or not, the dark ring looks much better than the official arrangement and, incidentally, it will add a little symbolism, depicting the outer darkness surrounding the light blue sky.

It will be a prolonged business, changing all our letterhead, banners and other possessions and we shall have to do it by degrees, as stocks run out and as we feel we can afford it. The President's Badge will not be changed but will retain the old name as a graceful anachronism. At least its colours will be "right" now!

IAS/CAI MEETING AND THE ASTRONAUTICS SYMPOSIUM

The IAS/CAI Meeting was held in Ottawa on the 23rd and 24th October; its entire programme was devoted to Aviation in the Polar Regions. On the Thursday and Friday of the same week, the Astronautics Section joined with the Canadian Astronautical Society and the David Dunlap Observatory and the Institute of Aerophysics, both of the University of Toronto, in a Symposium in Toronto on the subject of Interplanetary Explorations. I will report on these two meetings next month, when I shall be able to see them in better perspective than I can now.

CANADIAN ASTRONAUTICAL SOCIETY

At the abovementioned Symposium, our co-sponsor, the Canadian Astronautical Society, announced its intention to dissolve as a separate society and to merge its administration and activities with our own. Its decision stems directly from our election to change our name, to express, without any question or quibble, our concern with space; and it is a significant step forward.

The CAS was founded late in 1957, at about the same time as our Astronautics Section; both owed their birth to Sputnik I and the interest that that event inspired. The majority of its members – of the order of 200 – have lived in and around Toronto, although it has had quite a few members spread across Canada. It has been ably and energetically led and has done good work in the promotion of interest in the space sciences. Many will remember

its CHARM Project – Canadian High Altitude Research Missile – which, although never fired, achieved its intended purpose of providing a development activity for CAS members; the fact that this ambitious piece of experimental work was ever started is indicative of the enthusiasm that lay behind it.

But the CAS has been another society and the Canadian aerospace fraternity – or the number of available speakers for that matter – is not big enough to support effectively a multiplicity of technical societies with broadly overlapping interests. The CAS, the Astronautics Section and the Toronto Branch have got along quite well so far, only because they have been sensible enough to cooperate rather than squabble and to hold joint meetings rather than conflicting ones; but it made very little sense.

Negotiations with the CAS have been going on intermittently for years. In the course of these discussions we have been privileged to see the CAS membership lists and grading and we found that almost all of its members were perfectly well qualified for membership in the Institute; which made it all the more exasperating that we appeared to be unable to establish any common ground. It seems that the fact that we have elected to change our name – though the Council's recommendation was made for much wider reasons – has convinced the CAS that we are not exclusively air-breathing and this has at last decided the Society to throw in its lot with us.

Those of the CAS members who wish to transfer to the Institute will benefit from the wider and more consistent services which our larger organization and permanent Headquarters can provide. We, and particularly our Toronto Branch, will benefit from the removal of this competition – "competition" is much too strong a word; it is more a matter of confusion in the minds of the public and would-be members, conflict of programme activities etc.

BRANCHES

Quebec—29th September

Sixteen members of the Quebec Branch travelled to Montreal on the 29th September and visited the Canadair plant. They were flown there and back by Canadair and spent the day touring the plant and witnessing demonstrations by the CL-44 swing-tail and the CF-104. It was a very successful outing and our thanks are due to Canadair for their help and hospitality.

Montreal—20th September

Unfortunately the speaker arranged for the Montreal Branch September meeting was unable to come due to illness. However the 60 members who had turned up were not sent empty away; two films were shown, on the DC-8 Flight Simulator and Nordair's Arctic Operations from Yellowknife.

Halifax-Dartmouth—20th September

The Halifax-Dartmouth Branch met in the RCAF Officers' Mess, Anderson Square, on the 20th September. The meeting was devoted to the discussion of Branch business, followed by a showing of the film "Salute to Flight". There were 35 members present.

Ottawa—20th September

The Ottawa Branch was particularly honoured by a visit by Mr. Enea Bossi at its meeting on the 20th September. Mr. Bossi took part in a panel discussion on Man-powered Flight. The Chairman of the Panel was Dr. M. G. Whillans, and Mr. W. Czerwinski, Mr. R. J. Templin and myself were its other members. The discussion ranged rather generally over the field and the 50 members attending joined in, and showed a great deal of interest in this rather unusual subject. It was a very good meeting in this respect.

Toronto—27th September and 10th October

On the 27th September the Toronto Branch was addressed by Prof. H. S. Ribner of the Institute of Aerophysics, on "How Jets Make Noise". The meeting was held at De Havilland and there were 75 present.

Mr. J. Lukasiewicz, Chief of the von Kármán Gas Dynamics Facility, ARO, Inc. spoke to the Branch on the 10th October. His subject was "Hypervelocity Testing Techniques at AEDC". The attendance of 33 was disappointingly small. Mr. Lukasiewicz was formerly with the NRC Ottawa and was a member of the group that laid the groundwork for the formation of the CAI in 1953.

Edmonton—11th October

As had happened at Montreal in September, the speaker for the 11th October meeting of the Edmonton Branch was unable to come at the last moment. However a very good substitute was found in the person of Mr. H. Wilson, Chief Forecaster of the Combined DOT/US Arctic Forecast Team, who spoke on "Arctic Weather Data Gathering Processes and the Effect of Topography on Surface Winds". There were 28 people present and Mr. Hegstrom, the Branch Secretary, reports that it was a successful meeting and that Mr. Wilson was extremely interesting.

Calgary—12th October

Mr. A. H. Smolkowski of the SAIT, who won the Calgary Branch Student Award last spring, presented his prize-winning paper to the Branch on the 12th October at the RCAF Officers' Mess, Lincoln Park. There were 34 present. His paper was entitled "Drag of Aircraft Components"; this was followed by a short film on the JATO installation on the Canso.

As will be seen from these reports, the Branches are getting into their stride. Theirs is the most important part of the Institute's work and it is gratifying to know, as I do, that the Branch Programmes Committees seem to have been unusually vigorous in laying their plans for this season. Only lack of detail in some instances prevents us from listing more of their proposed meetings under our heading "Coming Events" in the Announcements; such listing without detail is rather pointless. But, from what I do know, things look promising.

ANNOUNCEMENTS

NEWS OF MEMBERS

A/M W. A. Curtis, Hon. F.C.A.I., was installed as the first Chancellor of York University, Toronto, on the 19th October.

J. L. Orr, F.C.A.I., has been appointed to head the new Directorate of Industrial Research, in addition to his present responsibilities as Director of Engineering Research, DRB.

G/C K. C. MacLure, A.F.C.A.I., has returned to Canada from Poland and is now located at the Pacific Naval Laboratories, DRB, Esquimalt, B.C.

S/L J. C. Henry, M.C.A.I., who was recently posted to Wright-Patterson AFB, has assumed the duties of Assistant Glider Project Engineer in the Dyna-Soar Development Integration Office.

J. E. Smith, M.C.A.I., Vice-President of Computing Devices of Canada Ltd., was recently appointed to the EIA Ad Hoc Committee on Research and Development.

D. J. Tynan-Byrd, M.C.A.I., is now attached to the Schilling AFB working on the Atlas F series Missile Activation programme.

W. L. Farrington, Associate, has left Bristol Aero-Industries Ltd., Montreal Div., to manage International Aero Sales Company in Montreal.

ADMISSIONS

The following is a list of admissions and advancement in grade of members during the month of October 1961.

Associate Fellow

H. S. Fowler
W. J. Potocki (*from Member*)

Member

M. A. T. Bamford
M. J. Baker (*from Technical Member*)
D. D. Dogherty
R. R. Finney (*from Technical Member*)
K. Grayson (*from Technical Member*)
K. I. M. Hale (*from Technical Member*)
W/C H. J. Hemsley
A. J. Hughes
M. A. Insley
W. E. Mossman
R. H. P. Timms (*from Technical Member*)
B. Vanderpol

Technical Member

R. R. Baker (*from Junior Member*)
F/O J. B. Feir (*from Student*)
R. W. Middlebrough
Lt. G. S. Moyer (*from Junior Member*)
A. K. Roberts
F/O J. A. F. Vieni (*from Student*)

Junior Member

R. J. Anderson (*from Student*)
L. E. Arnold (*from Student*)
W. S. Atkinson (*from Student*)
G. W. Couser (*from Student*)
W. T. Hancox (*from Student*)
L. G. Kiehlbauch (*from Student*)
J. A. Partica (*from Student*)

Student

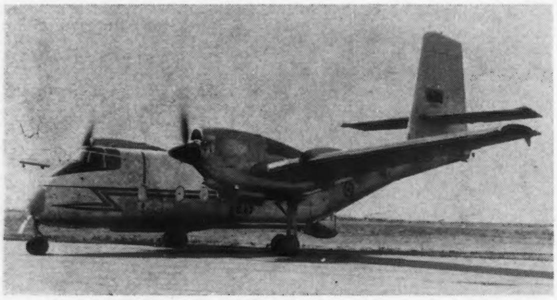
D. F. Lyster
A. J. Reynolds

Associate

W. C. Tate

SUSTAINING MEMBERS

De Havilland Aircraft of Canada Ltd. started flight testing the T.64-4 turboprop engine installation in the Caribou in September. The programme is being conducted jointly by General Electric and De Havilland, under the joint sponsorship of the USN and the DDP, and it is expected to be completed early next year.



The Caribou with T.64-4 engines installed

The Caribou was chosen as the test-bed because it offered such a wide range of characteristics suitable for testing the new engine. The basic aircraft in use is the original prototype of the Caribou Mk I, with no modifications to the airframe other than in the area of the nacelles. De Havilland designed a high efficiency intake duct which is proving successful.

Though the current programme is essentially directed towards the flight testing of the engine, De Havilland is studying a Caribou design based on using the T.64 powerplant.

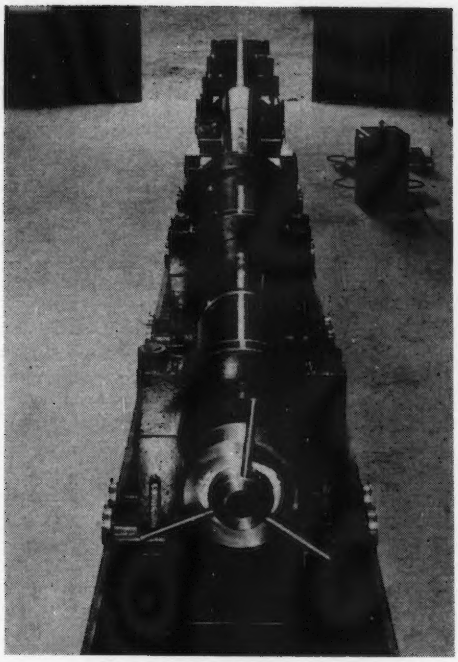
Computing Devices of Canada Ltd. are currently completing Phase 1 of the construction of an Aerophysics Research Laboratory, at Stittsville, Ontario, which will be the first such privately owned facility of its kind in North America. The new Laboratory will be equipped to conduct basic research in the following fields:

Impact and Penetration

Basic studies on the physics of hypervelocity impact investigations of the new phenomena of impact radiation.

Winged Vehicle Stability

The execution of atmospheric, controlled atmosphere and vacuum range tests on the stability and control characteristics of advanced re-entry vehicles at speeds between Mach 10 and 20.



CDC's double chamber light gas gun

Plasma Radiation and Communications

The use of high-g telemetry to study the effects of plasma on the transmission characteristics of manned and un-manned vehicles during the re-entry phase of the flight spectrum.

High-g Telemetry

The development of packaging techniques and instrumentation sensor and transducer equipment to provide more extensive in-flight model data and to advance the general design knowledge in the field of extreme acceleration survival electronics. Present packages survive and operate successfully after launch accelerations in the range of 150,000 to 500,000 g.

In addition to using gun launchers with current capabilities it is planned to continue the development of more advanced test methods for achieving better simulation and higher test speeds.

Initial launching equipment fitted in CDC's Aerophysics Laboratory consists of a number of 4 inch smoothbore guns which, with solid propellant charges, will permit tests of various projectiles and vehicles at speeds up to 8,000 ft/sec and a light gas gun (see cut) with interchangeable barrels of varying bore between ½ inch and 2 inches in diameter capable of launch speeds up to 30,000 ft/sec.

The Vertol Division, Boeing of Canada has announced the order of four Boeing Vertol 107 twin-turbine helicopters for the RCAF. This order will bring to six the total number of these aircraft, designated the CH-113, in RCAF service. They will be built at the Boeing plant at Morton, Pa., but will be finally accepted by the RCAF at Arnprior, Ont.

The helicopters will be highly specialized search and rescue vehicles with exceptional load-carrying abilities. With the aid of large capacity fuel tanks, they will be able to carry a 2,000 lb payload more than 650 statute miles before refuelling.

Power will be provided by two General Electric T58-8 engines, and cruising speed will be 150 mph. The helicopters will have seats for 26 fully equipped troops or will accommodate 15 litter patients.

Capable of all-weather operation in all conditions under which fixed-wing aircraft can operate and in temperatures as low as −65°F, the CH-113s will have rotor blade de-icing and will be equipped with a portable auxiliary power unit for standby electrical power in extreme cold climates. A modern electronic system for search and rescue operations will also be fitted.

Garrett Manufacturing Ltd. has begun deliveries of magnetic amplifiers and reactors to the Electronic and Ordnance Division of the AVCO Corporation, Cincinnati, Ohio. These units are designed to control electrical current within ± 0.2 amperes, under varying ambient conditions and varying electrical power supply.

The AVCO contract is the first one Garrett Manufacturing has received from a US firm outside the framework of its parent Garrett Corporation, of Los Angeles, since the latter initiated an extensive campaign to participate in the US-Canadian Defence Sharing Programme.

THE NAME OF THE INSTITUTE

A ballot on a recommendation by the Council that the name of the Institute should be changed to the "Canadian Aeronautics and Space Institute" was completed on the 20th October. The President appointed three voting members of the Institute to act as scrutineers and to count the votes, and the following is the text of their report, dated the 21st October, 1961:

"On the 5th October, 1961, the membership was asked to vote on the Council's recommendation that the name of the Institute should be changed to

Canadian Aeronautics and Space Institute

The ballot papers were to be returned by the 20th October.

We have today opened the envelopes and counted the votes. The results were as follows:

Number of votes cast	914
Number in favour	773
Number not in favour	133
Number of spoiled ballots	8

N. V. McEachern
J. C. Finlayson
H. C. Luttman"

This report was placed before the Council at its meeting on the 22nd October. The recommendation was considered to be adopted and a formal Amendment to the Bylaws will now be prepared for submission to the membership.

AMENDMENT OF THE BYLAWS

In the near future the voting membership will be asked to approve by ballot certain amendments to the Bylaws of the Institute. The amendments will be submitted in three groups, each group to be voted on as a whole. The groups are as follows:

Group (i) — The Name of the Institute

The change of name of the Institute, adopted by the membership in the ballot held during October, will necessitate the amendment of several Sections of the Bylaws —

simply to replace the words "aeronautical" and "aeronautics" by "aeronautics and space". Group (i) will comprise these amendments and others associated directly with the change of name; among the latter will be one to broaden the qualifications necessary for the grade of Associate and another to define a Sustaining Member more completely.

Group (ii) — Entrance Fee

This group is confined to an amendment to Section 1 of Article 10. The purpose of the amendment is to delete the now obsolete reference to membership in the Institute's parent societies and to give the Council discretion to waive entrance fee when it seems desirable to attract members from another, dissolving society. The Canadian Astronautical Society has announced its intention to dissolve and merge its interests with those of the Institute; the Council would like to waive entrance fee for those members of the CAS who wish to join the Institute and who do so within a specified period of time.

Group (iii) — Membership Dues

It is evident from the Financial Statement for 1960-61, published in the September 1961 issue of the Journal, that the financial structure of the Institute is inadequate to support it. Broadly speaking, the administration should be supported by the entrance fees and dues of individual members; meetings, publications and other activities should be substantially self-supporting, and Sustaining Members' contributions should be regarded as available to support such activities to the extent that they fail to support themselves. With the present dues structure and in face of generally rising costs this is not remotely realized, and the Council has regretfully concluded that an increase of dues in certain categories is necessary. This is the chief substance of the proposed amendment to Section 2 of Article 10 in Group (iii); however, in addition, the amendment relieves members resident in the USA from paying the full rates; in future they will benefit from the lower rates hitherto applicable only to members resident overseas.

Group (iii) also includes an amendment to Section 4 of Article 10, planned to encourage members joining the Institute in the fall, at the beginning of the active season.

APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.

Positions Vacant

Project Engineer (Electrical/Electronic): with at least five years experience in the design of airborne electrical and electronic installations. Duties will include preparation of schemes and supervision of a small section of draftsmen engaged on wiring and interconnecting diagrams, and advising a group of technicians working on the repair and overhaul of electronic equipment. Familiarity with RCAF procedures and drawing systems would be advantageous. Minimum educational requirement, British Higher National Certificate in Electrical Engineering, or equivalent. Age 30-45. Salary according to experience and qualifications.

Excellent benefit program after a short probationary period. Assistance with relocation expenses to be discussed with successful applicant. Apply to Manager Industrial Relations, Northwest Industries Limited, Box 517, Edmonton, Alberta.

COMING EVENTS

BRANCHES

Edmonton

13 December – RCAF Officers' Mess, Kingsway; *DC-8 Maintenance*, Speaker from CPA.

10 January – RCAF Officers' Mess, Kingsway; *VTOL*, Speaker from Okanagan Helicopters Ltd.

Ottawa

17 January – University of Ottawa; *Magnetohydrodynamic Propulsion*, Dr. P. Savic, NRC.

SECTIONS

Propulsion

19th-20th February – Ottawa, Details to be announced.


Something in mind ?